TECHNICAL MEMORANDUM

To: Devin Smith, Skagit River System Cooperative

From: Shawn Higgins, MS
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Tim Abbe, Phd, PG, PHG

Date: March 23, 2015

Re: Supplemental Hydraulic Analyses to support the Habitat Restoration Alternatives Assessment for the Barnaby Reach of the Skagit River

PROJECT BACKGROUND

The Barnaby reach of the Skagit River extends from the Illabot Creek confluence at River Mile (RM) 71.6 downstream to the State Route (SR) 530 bridge near Rockport at RM 67.8 (about 1 mile upstream of the Sauk River confluence) (Figure 1). Within the Barnaby reach lies the “Barnaby complex” that includes Barnaby Slough and Harrison Pond and was developed by the former Washington Department of Game to provide an off-site rearing facility for hatchery steelhead starting in the 1960s. This facility includes numerous dikes, culverts, fishways, and flow control structures that have greatly altered flow and habitat conditions in the reach. The Washington Department of Fish and Wildlife (WDFW) owns 456 acres encompassing the Barnaby complex and currently manages the site. WDFW has not used the facility for rearing since 2007 and currently have no plans to rear fish at the site in the future. The facility has fallen into disrepair and in some areas is creating barriers to fish passage. This has also created an opportunity to modify the facility to restore habitat conditions and natural processes within the reach. Land areas within the floodplain adjacent to the WDFW property have recently been acquired by The Nature Conservancy (323 acres) and Seattle City Light (418 acres) specifically to protect and restore habitat conditions.

Skagit River System Cooperative (SRSC) is coordinating the Barnaby Reach feasibility study in partnership with steering committee members Washington Department of Fish and Wildlife, The Nature Conservancy, and Seattle City Light to evaluate project alternatives and develop conceptual designs for preferred restoration actions. The Steering Committee identified four conceptual restoration alternatives: (1) restoring fish passage, (2) removing infrastructure at Barnaby Slough, (3) removing infrastructure at both Barnaby Slough and Harrison Pond, and (4) actively restoring a portion of the Skagit River flow into Barnaby Slough to create a perennial side channel. To meet the intent of Alternative 4, the inlet to the perennial side channel would be excavated to connect to Barnaby Slough and 5 engineered logjams (ELJs) would be placed in the mainstem to create a backwater effect and direct flow into the channel inlet. The Habitat Restoration Alternatives Analysis (SRSC and NSD, 2014) evaluated the reach hydraulics, geomorphic response potential, habitat for fish and wildlife, and described the anticipated benefits and impacts associated with each alternative.

SRSC previously contracted with Natural Systems Design, Inc. (NSD) to develop a hydraulic and geomorphic assessment to support a habitat alternatives analysis and to identify possible risks to private property and public infrastructure in the reach. The assessment developed a 2-dimensional (2D), steady state hydraulic model and simulated several different flow scenarios for the Skagit River between WSDOT Highway 530 and Illabot Creek. Initial hydraulic model runs from the Alternative 4 simulation (mainstem reconnection to Barnaby Slough) indicated that the backwater effect from proposed main channel ELJs increased flood elevations upstream from Illabot Creek confluence and outside the model boundary during the 2- and 100-year flood event. In addition during the 2-year flood event, increases in floodplain connectivity within near Lucas and False Lucas Slough resulted in minor increases in flood elevations near Martin Road. To better understand flood impacts and also the potential flood reduction benefits for alternative 4, additional analysis of the proposed condition hydraulics were requested to be completed by NSD. Additional analyses also incorporated data from the newly constructed WSDOT project at MP 100.7 and new survey information near the Barnaby Slough. Additional analyses completed include a hydrologic assessment, 2D unsteady flow simulations and a 1-dimensional (1D) hydraulic analysis. This technical report is intended to supplement analyses from the feasibility study and to clarify anticipated upstream/downstream effects in regards to flood hazards specific to Alternative 4.

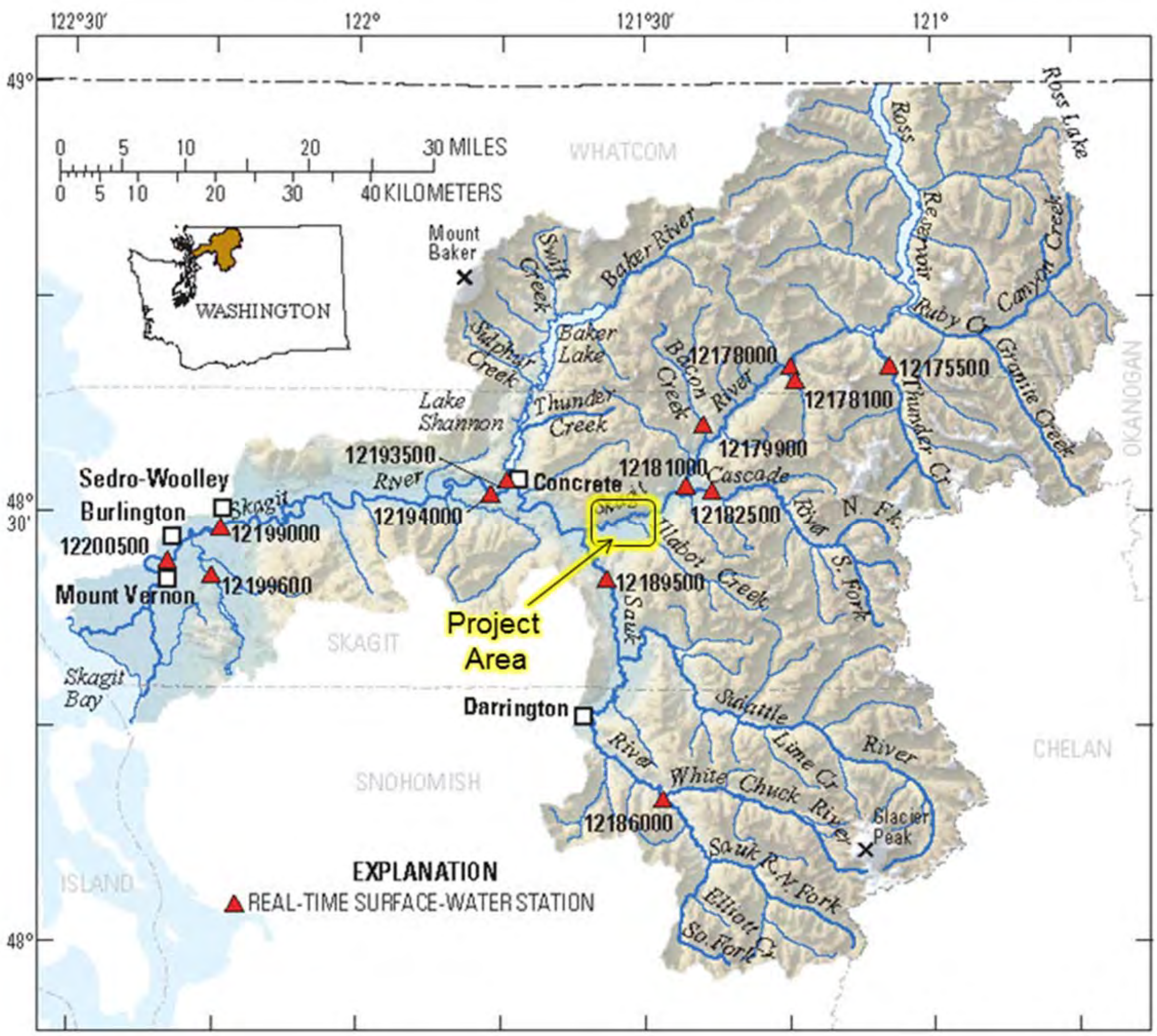

Figure 1. Map of the Skagit River watershed showing the location of the project reach, hydrologic features, and USGS stream gages. Map source: USGS.

HYDROLOGY

The watershed upstream of the project reach is a steep, mountainous area encompassing 1,655 square miles with headwaters in the North Cascades and approximately 8,000 feet of vertical relief (Figure 1). Annual precipitation totals average approximately 70 inches in lowland areas but increase to over 150 inches in the headwaters. The hydrologic regime of the project reach is characterized by a seasonal variation with low flows in the late summer and early fall, higher winter flows with flood peaks in response to heavy rainfall, and a spring/early summer snowmelt period. The largest floods are created by winter rainfall events associated with atmospheric rivers that concentrate moist air from the tropics into narrow plumes that are conducive to enhanced orographic precipitation upon landfall (Neiman et al., 2011).

The mainstem Skagit River is impounded by three dams owned and operated by Seattle City Light in the gorge upstream of Newhalem (RM 96). The Skagit River Hydroelectric Project has regulated flow at the Gorge Dam and Powerhouse since 1924, Diablo Dam since 1929, and Ross Dam since 1940. Collectively, the contributing drainage area upstream of the three dams totals 1,159 square miles and is 70% of the watershed area above Rockport. The Cascade River, draining a watershed area of 172 square miles, is the largest unregulated tributary to the Skagit River upstream of Rockport. The regulated flow regime resulting from dam operation tends to diminish the frequency of larger bed mobilizing flows.

Determining estimates of peak streamflow and flood hydrographs within the project area is difficult due to discontinuous gage records, distance to available gages, tributary inflow between gauge locations, and the effects from hydro-electric projects. USGS does maintain a network of streamflow monitoring stations in the Skagit River watershed that provide historical data for quantitative description of hydrologic parameters at those locations (Table 1). The gage on the Skagit River near Rockport (#12184700) was recently installed in the project reach along right bank opposite the Barnaby Complex (300 feet upstream of Swift Creek) and has recorded stage (water level) since August 31, 2014. The Rockport gage is the most proximate and accurate gage to develop peak streamflow estimates and flood hydrographs for this project but is currently a stage-only station that does not report streamflow. The nearest gage recording streamflow on the Skagit River to the project reach is near Marblemount (#12181000) and at RM 78.7 and reflects a 17% decrease in drainage area excluding tributary inflows from the Cascade River. The next nearest gage recording streamflow on the Skagit River downstream of the project reach is near Concrete (#12194000) at RM 54.1 and reflects a 40% increase in drainage area including tributary inflows from the Sauk River which is the largest unregulated tributary in the Skagit River watershed. Peak flow estimates from the USACE (2010) are summarized for the project reach in Table 2.

To reduce uncertainties with transforming historical records from available gage data and to match methodology from the previously completed steady state hydraulic analysis, the 2-year flood hydrograph used in this unsteady 2D hydraulic analysis was obtained from output data from the USACE Skagit River Flood Damage Reduction study and model, as shown in Figure 2. As part of the USACE study, an unsteady HEC-RAS model was developed for the entire Skagit River watershed that accounts for flood routing and storage effects from major Skagit River tributaries and dams. To validate the USACE flood hydrograph, streamflows within the project areas were calculated using 15-minute instantaneous USGS gage records during an actual flood event that occurred on December 10, 2010. Analysis of peak flow records at the Marblemount and Concrete gages indicate this flood event was approximately a 2-3 year peak flow event. Estimates of streamflows within the project area were calculated using the following two methods:

1. BARNABY CALC1 = CONCRETE – BAKER – SAUK
2. BARNABY CALC2 = MARBLEMOUNT + CASCADE

Results from this analysis are shown in Figure 2 and indicate the USACE flood hydrograph matches the magnitude, duration, and rising/falling slope within acceptable tolerances. Main differences between the

USACE flood hydrograph and streamflow estimates for the 2010 event, include a higher starting baseflow and a double peak event. Possible explanations for differences in streamflow calculations can be attributed to additional tributary input not accounted for at gage locations, travel time between the different gage locations, and uncertainty/error of discharge estimates but were not investigated as part of this analysis. If deemed of value, future unsteady flow hydrographs and runs could be modified to begin at a lower baseflow condition to provide a range of results over a more complete/typical flood hydrograph. For this analysis, the results of the 2D unsteady analyses are intended to inform an evaluation of relative downstream flood risks (difference between existing and proposed conditions) for which the USACE hydrograph is considered sufficient. It should be noted, the effects for a full range of flood events was not analyzed as part of this project. However by evaluating the effects during the 2-year (frequent smaller flood event) and the 100-year (infrequent major flood event) the range of flood events can be reasonably surmised.

Table 1. USGS streamflow gaging stations in the project vicinity.

WATERCOURSE	LOCATION	GAGE NUMBER	TYPE	YEARS OF RECORD	BEGINNING OF RECORD
Skagit River	Marblemount, WA	12181000	Real-time temperature, discharge, gage	50	1943
Skagit River	Rockport, WA	12184700	Gage (stage only)	<1	2014
Skagit River	Concrete, WA	12194000	Real-time discharge, gage	95*	1815**
Cascade River	Marblemount, WA	12182500	Real-time discharge	64*	1815**
Sauk River	Sauk, WA	12189500	Real-time discharge, gage	86	1911
Baker River	Concrete, WA	12193400	Real-time discharge	5	2008

* *Record discontinues for long durations*

** *Historical records determined from estimates of flow based upon re-constructed flood markers*

Table 2. Summary of flood frequency statistics for the Skagit River at Rockport (upstream of Sauk River confluence). Source: USACE (2010), as cited in NHC (2011).

Recurrence interval (years)	peak flow* (cfs)
2	36,000
5	46,200
10	55,000
25	68,100
50	79,300
100	92,500

FLOOD IMPACT EVALUATION

To better evaluate changes in flood elevations additional hydraulic modeling was performed specific to Alternative 4. Initial 2D model simulations for Alternative 4 indicated an increase in flood elevations upstream of the project area during the 2- and 100-year flood events and a minor increase in flood elevations downstream of the project area and near Martin Road during the 2-year flood event. The evaluation of upstream effects was performed using a 1D HEC-RAS hydraulic model for the 100-year flood event. A 1D model was chosen for this analysis due to anticipated inundation of the floodplain creating primarily downstream flow (1D) patterns and the length of river channel likely affected making detailed 2D model mesh (similar to what has been utilized) impractical and cost prohibitive. 1D hydraulic models are well formulated to evaluate large magnitude floods, reach effects, and are the general standard for flood impact evaluations. The evaluation of downstream effects was performed using a 2D unsteady model that utilized the previously developed model mesh. A 2D model was chosen for this analysis to better characterize the complex flow patterns within Lucas and False Lucas slough, type and extent of current flooding near Martin Road, and account for possible flood attenuation benefits and storage associated with Alternative 4. 2D hydraulic models are better formulated to evaluate site specific concerns and complex flow patterns than 1D models when good topographic data is available. Both hydraulic models utilized are appropriate for evaluation of flood impacts and FEMA regulatory requirements.

UNSTEADY 2D HYDRAULIC ANALYSIS

The primary objective of NSD's 2D unsteady hydraulic analysis was to evaluate flow patterns, hydraulic parameters, and inundation extents to characterize current riverine conditions during frequent lower magnitude flood event and evaluate the effects of the proposed Alternative 4. Previously completed model runs were performed in a steady state (discharge does not vary with time) and unsteady flow model runs (discharge varies with time) were completed to more accurately characterize flow conditions during a simulated frequent flood events. Steady state analyses assume a constant flow rate through the length of the simulation resulting in a lower hydraulic gradient, lower velocities, and higher flood elevations and are thus considered conservative and appropriate for flood studies. However, unsteady state analyses utilize a flow hydrograph representative of real or simulated floods that allows for storage effects within floodplain to be considered and more accurately characterizes the flow conditions during the rising and falling limb of the flood hydrograph. Hydraulic models were created representative of existing using the Hydronia's RiverFLOW2D Plus and Aquaveo SMS v11.2 computer software. RiverFLOW2D is a two-dimensional finite volume computer model that provides depth averaged hydraulic parameters at nodes within a triangular model mesh domain. RiverFLOW2d determines depth averaged hydraulic parameters by solving the shallow water equations resulting from the vertical integration of the Navier-Stokes equation. The Navier Stokes equation is derived from applying Newton's Second Law (Force=mass*acceleration) to fluid motion, and is generally expressed as:

$$\overbrace{\rho\Big(\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{\mathbf{v}\cdot\nabla\mathbf{v}}_{\text{Convective acceleration}}\Big)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu\nabla^2\mathbf{v}}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{\mathbf{f}}_{\text{Other body forces}}.$$

Where ρ = fluid density

μ = dynamic viscosities

p = pressure

$\nabla =$ del operator (abbreviation for derivative (gradient)of 3D vector field)
f = term representing body forces acting on the fluid (per unit volume)

SMS is a GIS based program that creates the triangular model mesh, model input files, and displays model results. The following sections provide more in-depth information on specific components of our hydraulic analysis, data development, and results.

Methods

An existing condition hydraulic analysis was completed to inform the understanding of current hydraulic and geomorphic processes within the project area and to compare results with proposed condition modeling, to evaluate the effects of Alternative 4 restoration elements. The existing hydraulic analysis was conducted for the 2-year hydrograph, utilizing the shape and duration as described in the previous section, and increased to match the magnitude of the 2-year peak discharge utilized in previous 2D model simulations. All model runs were performed in unsteady state (discharge does varies with time) with a non-deformable bed (no adjustments for scour, sediment transport and deposition).

Model Topography

2D hydraulic models developed for this project utilize a combination of topography data sources that include LiDAR, channel bathymetry, and ground survey. LiDAR data used for this project was acquired for SRSC by Terrapoint in 2005. As part of the Illabot Creek project, it was determined that portions of the 2005 LiDAR produced elevations higher than actual ground elevations. LiDAR elevations were adjusted -0.9-feet (lower) per a comparison with surveyed elevations within the project area (SRSCa, 2013). Channel bathymetry data used for this project was acquired by Wilson Survey and Engineering in April 2013. Surveys were performed via transects of the main channel, Barnaby Slough, Harrison Pond, and Boh's Slough using RTK GPS technology and a boat mounted echosounder. Channel bathymetry was interpolated in between 31 transects. Ground survey used for this project was acquired by SRSC staff for features (top of bank, toe of slope, infrastructure control elevations) near Barnaby Slough and Harrison Pond, Lucas slough channel thalweg, and SR 530 Bridge over Boh's Slough. Information on survey methods and data acquisition is provided by Summary of Data Sources for Hydraulic Modeling within the Barnaby Reach Project Site (SRSC 2013b). Since the completion of the Feasibility analysis, new survey information was acquired by SRSC near the Barnaby complex and Skagit River main channel, as shown in Figure 3. Information in these areas was acquired from Wilson Survey and Engineering in August 2014 and WSDOT. To utilize the various data sources in the hydraulic analysis, a composite digital terrain model (DTM) was developed in AutoCAD Civil3D that merged data sources into one data file. The horizontal and vertical datum of all data utilized and referenced in this report is Washington State Plane Coordinates North Zone NAD83/91 feet and NAVD 88-feet, respectively.

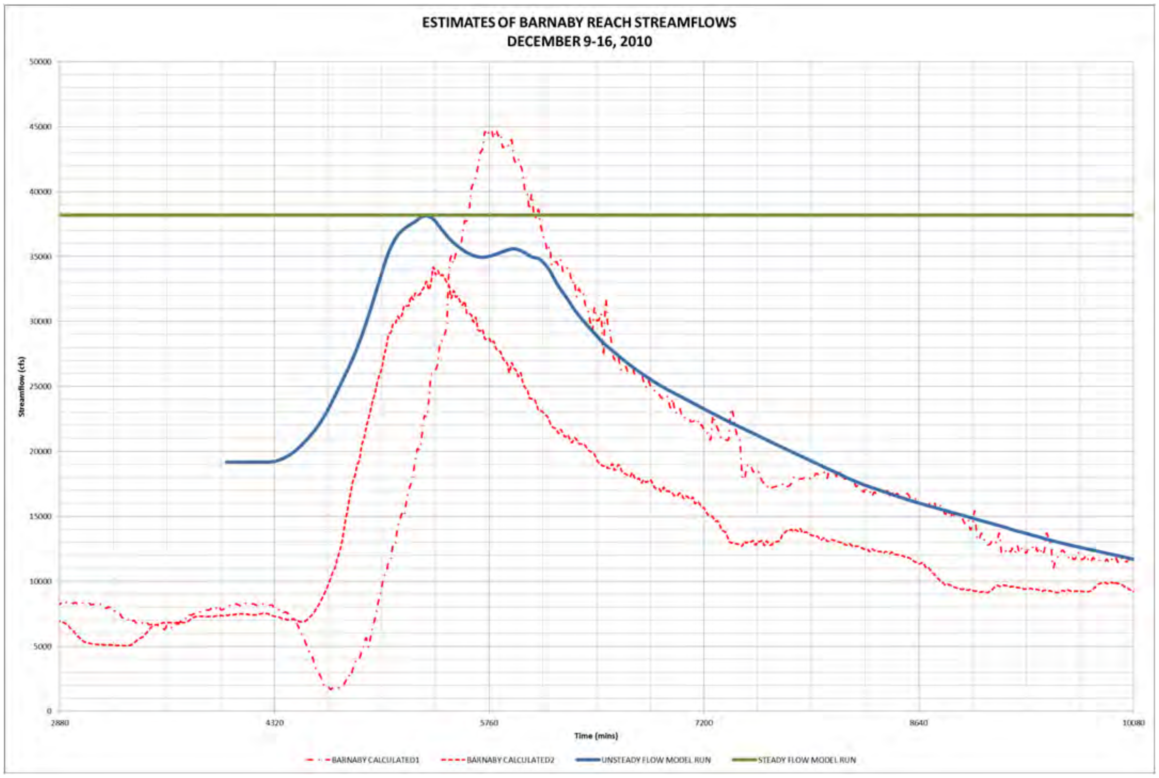

Figure 2 - Comparison of USACE unsteady hydrograph to 2010 gage estimates

Mesh

A mesh or wireframe is a key component to any 2D hydraulic model. The model derives one depth averaged flow velocity (direction and magnitude) at each node of the 2D (x-y) mesh. The mesh is composed of nodes and elements that are coded with elevation and roughness values needed to run the computational routine. RiverFlo-2D Plus utilizes a flexible tri-angular finite volume mesh to solve for conservation of volume and momentum in the x and y directions at each node (representing depth average). The model mesh begins approximately 1000 feet downstream of the SR 530 bridge and extends upstream 3 miles near the confluence with the Illabot Creek complex. For this project the model mesh utilized approximately 400,000 triangular elements and 200,000 nodes. The governing equations are applied at each node in an iterative routine until converging on a solution that achieves conservation of mass and energy to within an acceptable error.

To create the model mesh, a map consisting of arcs and regions delineating the channel, floodplain features, and material types was developed using Aquaveo's Surface-water Modeling System (SMS) software. Arcs were drawn along significant topographic features (top of bank, bars, side channels, roadways) and changes in roughness (forest type, sloughs, logjams, cleared areas). Arcs function as breaklines during the mesh creation process to ensure the model mesh is an accurate representation of the channel/floodplain topography and to create regions within the map that different roughness values can be assigned to. The spacing of nodes along an arc also functions to affect the density or refinement of the model mesh. The level of refinement of a model mesh is an important consideration during 2D modeling, as a finer (more dense) mesh creates more accurate representation of the channel and floodplain topography, reduces model instability issues, but increases model computation time. For this project, the spacing of nodes along each arc was adjusted to increase node density in areas of interest to between 10- and 20-feet (main channel, Barnaby Slough, Harrison Pond, False Lucas Slough, etc.) and reduced in other regions to between 50- to 100-feet (out edge of floodplain, forest regions, etc.). In this way, the model mesh was optimized to provide detailed information in areas of interest while also balanced with reduced computational times to allow more iterations of the model to occur. With the exception of new survey near Barnaby slough, the model mesh for the completed unsteady runs was developed to match the model mesh used for the previously completed steady state model runs.

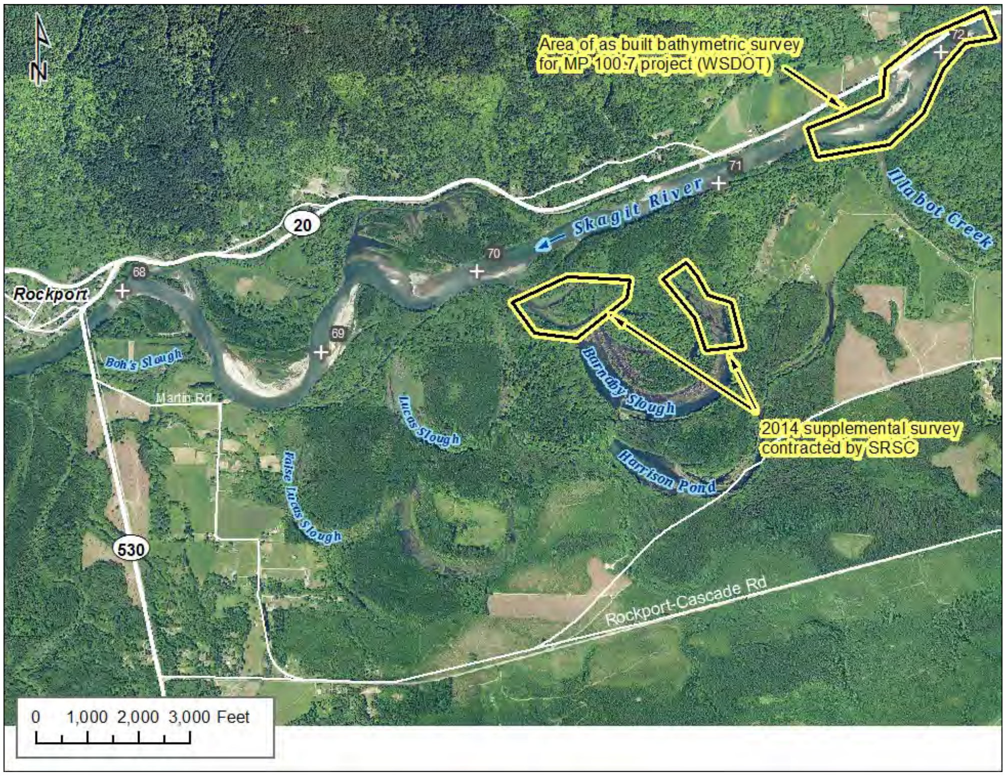

Figure 3 - Areas of new survey incorporated in the unsteady model and HEC-RAS model runs

Roughness

Hydraulic analyses require an assessment of the resistance (drag force) the ground surface and other physical features exert against movement of water. This drag force is commonly referred to as roughness. The most accepted method to assess roughness uses the Manning's n resistance factor (Chow, 1959). Common factors that affect roughness values include: channel sediment size, gradation, and shape; channel shape, channel meandering, both bank and floodplain vegetation, obstructions to flow, flow depth, and flow rate. 2D hydraulic models explicitly calculate momentum losses caused by channel shape, meandering, and floodplain topography not normally accounted for in 1D hydraulic models. As such, Manning's n values in 2D models can generally lower (up to 30%) than those normally used for 1D hydraulic models (Hydronia, 2012). Manning's n values for this project were set for different roughness types using GIS mapping provided by SRSC, recent aerial photographs and in accordance with standard hydraulic reference manuals (Chow, 1959; Barnes, 1967; Hicks and Mason, 1998). Model roughness values for the unsteady runs were set to exactly match the roughness values used for the previously completed steady state model runs and are shown in Table 3.

Boundary Conditions

All hydraulic models require the user to input a known boundary condition at the upstream and downstream extents to begin the computational routine. The boundary conditions for the unsteady model runs were set as shown in Table 4, below. The 2-year flow runs utilized a simulated flood hydrograph from the USACE Skagit River Flood Damage Reduction study and model. The boundary condition for unsteady runs was changed from a specific water surface elevation, as utilized in steady state runs, to a free outflow condition that allows the water surface adjust to changes in discharge associated with the rising and falling limb of the flood hydrograph. This results the downstream boundary water surface elevation being approximately 2 feet lower in the unsteady runs that previously complete steady state model runs.

Table 3. Roughness values used to characterize different feature types in the 2D hydraulic model simulation.

ROUGHNESS TYPES	MANNNG'S N VALUE
Channel_main	0.022
Channel_side	0.026
Channel_slough	0.032
Gravel bar	0.046
Gravel bar_vegetated	0.07
Wetland (all types)	0.07
Forest (conifer, deciduous, mixed, dead)	0.12
Forest_clearcut	0.08
Clearing_pasture	0.05
Logjam	0.15
Road_paved	0.016
Road_gravel	0.035

Table 4. Model boundary conditions.

FLOW EVENT	UPSTREAM DISCHARGE (CFS)	DOWNSTREAM WATER SURFACE ELEVATION
2-YEAR PEAK	USACE flood hydrograph RM71.2	Free outflow

Results

Results from the unsteady model runs are attached to this report in Appendix A and are described below;

- Unsteady model results predict 1 to 2 feet lower water surface elevations than previously completed for the steady state simulations. This results in slightly less inundated area for both existing and proposed conditions than previously shown. Main reasons for differences between unsteady and steady state runs can be attributed to;
    - Steady state model runs utilized a constant 38,200 cfs throughout the entire mesh over a 6 hour period, whereas the unsteady model runs routed a realistic flood hydrograph through the mesh over a period of 96 hours, during which the peak discharge of 38,000 cfs only persisted for one hour. During unsteady state model runs there is a larger hydraulic gradient which increases the river's capacity to convey flow on the rising limb of the hydrograph. The higher hydraulic gradient of the unsteady model also results in higher maximum streamflow velocities (1-4 feet/second increase over steady state).

  - The river channel is more entrenched within its upper reach near RM 71 and becomes more connected to its floodplain in the lower reach near RM 68. This change in channel confinement and floodplain topography results in a three percent (1,020 cfs) attenuation or reduction of the flood peak in unsteady model runs from the upstream to downstream end of the model domain, as shown in Figure 4. These results provide a more accurate assessment of flood wave propagation within the project area, demonstrating the project will not increase flooding near Martin Road as previously shown in the steady state simulation.
  - The free outflow downstream boundary condition used in the unsteady model resulted in a two foot lower water surface. This difference has only a local effect near downstream model boundary (downstream of Highway 530 to RM 68)
- Proposed condition unsteady model results indicate similar relative effects from project elements as steady state results. Engineered logjams (ELJs) within the main channel create a local backwater effect that increase flow depths 0.5 to 4 feet within the main channel and divert flow into Barnaby, Harrison, and Lucas slough. ELJs within the main channel and the split flow into the Barnaby channel also result in a reduction of main channel velocities between 0.5 to 6 feet/second.
  - Most of the water that enters into Barnaby channel flows out through Lucas Slough, with less flow entering False Lucas Slough than steady state model runs. This result explains much of the reduced flood inundation on private parcels near Martin Road that had previously been predicted in the steady state simulation. The unsteady model runs demonstrates the project will not increase flood risk in this area.
- Flow distribution between the Skagit River and Barnaby channel varies between 14 to 28% and is dependent on the total streamflow and stage, as shown in Figure 5. During higher Skagit streamflows, ELJs within the main channel have a larger effect on hydraulic conditions at the inlet location resulting in the Barnaby channel conveying a larger distribution of the total flow. During lower streamflows, ELJs within the main channel have less of an effect on hydraulic conditions at the inlet location resulting in the Skagit River mainstem conveying a larger distribution of the total flow.
- Flood hydrographs for existing and proposed conditions near Martin road and RM 68.5 show that Alternative 4 (proposed condition) will not provide a significant flood attenuation benefit (Figure 6). While there are small differences in the existing and proposed hydrographs they are within the expected tolerance of the model and not considered significant.

Figure 4 - Flow hydrographs within project sub-reaches. Note 3% reduction in peak flow (1,020 cfs) within Skagit River from upstream to downstream model domain.

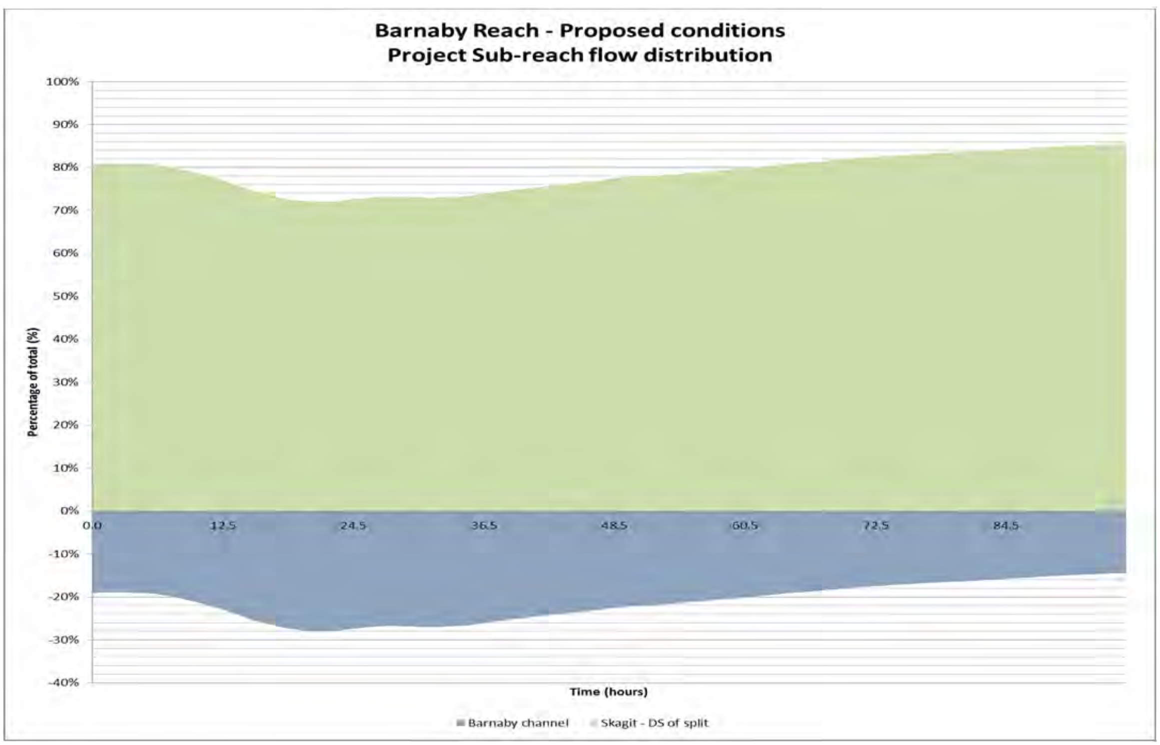

Figure 5. Distribution of flow between main and Barnaby channel.

Figure 6 - Flood hydrograph comparison at Martin Road (RM 68.6)

1-D HYDRAULIC ANALYSIS

The objective of this task is to evaluate potential flood impacts associated with proposed management actions to restore floodplain connectivity between Barnaby Slough and the mainstem Skagit River as described for Alternative 4 in the Habitat Restoration Alternatives Assessment. The 2D model developed for the Alternatives Assessment provides a detailed characterization of hydraulic parameters within the project area; however, the spatial coverage of the 2D model is limited to an approximately 4 mile reach with an upstream boundary near the tributary junction with Illabot Creek (RM 71.5). In order to fully identify any potential upstream increase in water surface elevation during larger magnitude and infrequent floods resulting from proposed actions, a 1D hydraulic model developed using the U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) is utilized to assess hydraulic parameters along an extended reach beginning at the Sauk River confluence and continuing upstream to the junction of the Cascade and Upper Skagit Rivers near Marblemount (RM 78). The 1D hydraulic analysis performed using HEC-RAS simplifies the reach geometry into a series of cross-sections and averages out some of the localized variability and complexity shown in the 2D model results. HEC-RAS is capable of modeling split flow junctions, such as proposed for the Barnaby Reach as part of Alternative 4, and is a standard modeling tool in use for floodplain management applications. Flood impacts are assessed by comparison of existing and proposed (Alternative 4) water surface profiles. Resulting changes in water surface elevations for the 100-year recurrence interval flood are mapped using GIS tools to quantify the potential increase in floodplain inundation.

Model Development

NSD developed a hydraulic model using HEC-RAS v4.1.0 for an 11 mile segment of the Skagit River upstream from the Sauk River confluence to the junction of the Cascade and Upper Skagit Rivers near

Marblemount. Steady flow water surface profiles were computed in HEC-RAS from one cross-section to the next based on solution to the 1D energy equation using an iterative procedure called the standard step method. The energy head loss between two cross-sections is comprised of friction losses (Manning's equation) and contraction/expansion losses (coefficient multiplied by the change in velocity head). Comparison of water surface profiles derived for both existing and proposed (Alternative 4) conditions shows the relative flood impact associated with the proposed action.

Geometric data representing existing conditions was developed using a river system schematic that included a split flow junction at RM 70.9 to calculate the distribution of flow between the mainstem Skagit River and the meandering flowpath along Barnaby Slough that reconnects downstream near RM 70. The split flow reach configuration best facilitates comparison of existing hydraulic parameters to proposed conditions that include restoration of perennial floodplain connectivity to the historical channel alignment occupied by Barnaby Slough. The Skagit River is represented by a series of 55 cross-sections with an average longitudinal spacing of less than 1,000 feet (less than two times the average bankfull channel width). An additional 11 cross-sections represent the split flow reach through Barnaby Slough at a similar longitudinal spacing with cross-section endpoints aligned to the left bank of the mainstem channel as shown in Figure 7. A lateral structure was entered to connect the mainstem channel cross-sections to the overbank sections of the adjoining split flow reach through Barnaby Slough. The lateral structure accounts for floodplain connectivity and lateral exchange between the mainstem channel and Barnaby Slough downstream of the split flow junction. A weir coefficient of 0.5 is applied as the landscape feature modeled as a lateral structure does not really function as a weir; however, water must flow over naturally high ground to access the adjacent floodplain area.

Cross-section data are derived from a Digital Terrain Model (DTM) comprised of multiple data sources including:

- Topographic surveys by SRSC around the Barnaby Complex in 2013 and 2014;
- Bathymetry surveyed collected by Wilson Engineering in the main channel and targeted portions of the floodplain (e.g., Barnaby and Harrison Sloughs) in 2013 and 2014;
- Bathymetry surveyed by WSDOT immediately upstream of the Barnaby subreach in 2014 for the as-built survey of the recently constructed bank protection project along SR 20 at MP 100.7; and
- LiDAR based Digital Elevation Models (DEMs) derived from data collected in 2005 and 2006 (2005 LiDAR data were assumed to be more accurate [see description of topographic data in the Alternatives Assessment] and supplemented by the 2006 LiDAR data from USGS for areas outside of the region covered in the 2005 LiDAR DEM)

Within the segment of the HEC-RAS model that overlaps with the 2D hydraulic analysis (RM 67.5 to 71.5), cross-sectional geometry is extracted directly from the DTM developed for the 2D model. River channel cross-sections outside of this area are represented with high resolution bathymetric data only as far upstream as the MP 100.7 project site along SR 20. Upstream of the bend at MP 100.7, cross-sectional bathymetry was derived from 1975 surveys for the original Flood Insurance Study (FIS) for Skagit County (FEMA, 1989), that was merged with the cross-sectional data extracted from the LiDAR DEM.

Roughness values used to estimate friction losses for each cross-section were represented by Manning's roughness coefficient (n) using the same classification developed for the 2D analysis (Table 3). Horizontal variation of n-values for each section is derived from an overlay of the roughness polygons created for the 2D analysis. The horizontal variation of n-values in the reach outside of the area covered by the 2D analysis is estimated from an overlay of cross-section alignments with recent aerial imagery and aims to maintain a consistent classification of roughness types used in the project area for the 2D analysis. A uniform adjustment factor was applied to scale roughness values in the HEC-RAS model and account for energy loss due to planform variations which is represented in the domain geometry of 2D models but not for 1D calculations (Horrit et al., 2002). A range of adjustment factors between 1.0 and 1.5 was evaluated through a comparison of the water surface profile generated from the 2D analysis and a factor of 1.2 was selected as the best match with predicted water surface elevations between the 1D and 2D models.

Areas of ineffective flow were designated to identify locations in which water is expected to pond, but that the velocity of that water, in the downstream direction, is near or equal to zero. Within the Barnaby Reach, ineffective flow was primarily designated for portions of Barnaby and Harrison Sloughs that are obstructed by dams which pond water within the floodplain and obstruct downstream conveyance.

The steady flow water surface profile was computed for the 100-year recurrence interval peak flow (Table 2). A downstream boundary condition was specified to match the maximum water surface elevation for the Sauk River confluence derived from results from the Skagit River Flood Risk Management Study (USACE, 2011). The steady flow water surface profile computation utilized an optimization routine to iteratively solve for the distribution of flow between the mainstem Skagit River and the flowpath along Barnaby Slough.

A proposed conditions model was then developed in HEC-RAS to represent design criteria for Alternative 4 as defined in the Habitat Restoration Alternatives Assessment (SRSC 2014). The inlet channel to Barnaby Slough downstream of the split flow junction was defined by extracting cross-sectional geometry from the proposed conditions DTM developed for the 2D model of the project reach (Figure 8). Ineffective flow areas within Barnaby and Harrison Slough were removed for the proposed conditions model to reflect active conveyance through these floodplain features following removal of infrastructure that acts to dam the sloughs under existing conditions. A series of six ELJs are added within the mainstem channel segment using blocked obstructions to modify existing cross-sectional geometry and modifying the horizontal distribution of roughness values to account for additional roughness produced by the wood jams (Figure 9). Last, the contraction/expansion ratios of the mainstem sections modified by ELJ obstructions were increased to account for the rapid changes in cross-sectional area created by addition of the ELJs.

Resulting changes in water surface elevations for the 100-year recurrence interval flood are mapped using GIS tools to quantify the potential increase in floodplain inundation. Hydraulic model results from HEC-RAS have been imported to GIS with use of the HEC-GeoRAS extension for ArcGIS. GeoRAS processes the water surface profile data from HEC-RAS and produces a raster surface of water surface elevation for use in floodplain mapping. Note that 1D hydraulic model results assume a linear slope between cross-sections; thus simplifying some of the hydraulic complexity shown in the 2D model results. Map algebra was utilized to extract the difference between existing and proposed model outputs to show the longitudinal distribution of changes in the water surface profile as a result of proposed management actions defined for Alternative 4.

Results

The water surface profiles computed from the 1D hydraulic analyses with HEC-RAS are plotted in Figure 10. The simulation of proposed actions (Alternative 4) shows a relative change in water surface elevation ranging between a 1.0 foot decrease and a 0.8 foot increase (Figure 11). In general, water surface elevation of the proposed conditions simulation decreased within the project reach adjacent to the Barnaby Complex as a greater proportion of the flow is routed along the meandering flowpath of Barnaby Slough. The additional roughness and constriction of the mainstem cross-sectional area by ELJs near the split flow junction in the upstream portion of the project reach, produces a 0.8 foot increase in water surface elevation. The backwater effect from the rise in water surface at the split flow junction declines to less than 0.1 feet at the outlet of Illabot Creek. The model predicts that the proposed conditions backwater will extend upstream a total distance of 6,500 feet to the bend abutting SR 20 at the recently constructed MP 100.7 bank protection project (Figure 11).

GIS maps of floodplain inundation based on 1D hydraulic model output with HEC-RAS are shown in Appendix B. Observable changes in floodplain inundation are generally limited to the segment downstream of the Illabot Creek confluence. GIS comparison of the existing and proposed floodplain areas shows a total increase in floodplain inundation of 9 acres.

Results of the HEC-RAS model simulations for the 100-year recurrence interval flood provide information to evaluate the potential flood impacts on property upstream or downstream of the project area. The regulatory floodplain was mapped in an earlier Flood Insurance Study (FEMA, 1989) that has since been updated; however, the newest floodplain maps have not been made effective. An excerpt of the Preliminary Flood Insurance Rate Maps (FEMA, 2010[1]) covering the project vicinity is attached as Appendix C. Simulated water surface elevations from the HEC-RAS model developed for the Barnaby Floodplain Project were compared to base flood elevations shown in Preliminary Flood Insurance Rate Maps with good agreement (less than 1 foot of difference at a section through Barnaby Slough).

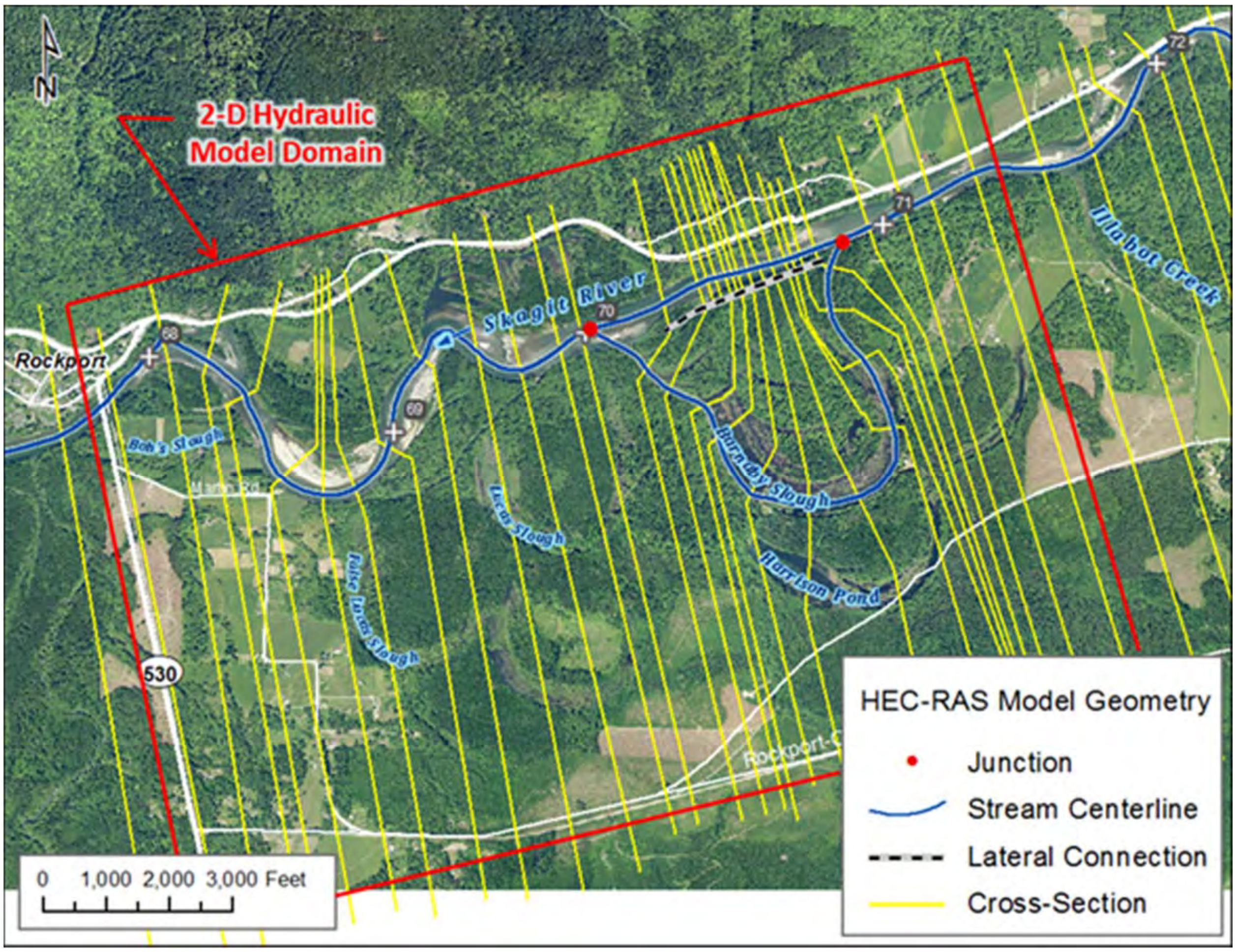

Figure 7. HEC-RAS model schematic showing cross-section locations and the split flow reach representing the distribution of flow through the project reach.

[1] http://www.skagitcounty.net/Departments/PlanningAndPermit/FEMAfloodstudy.htm

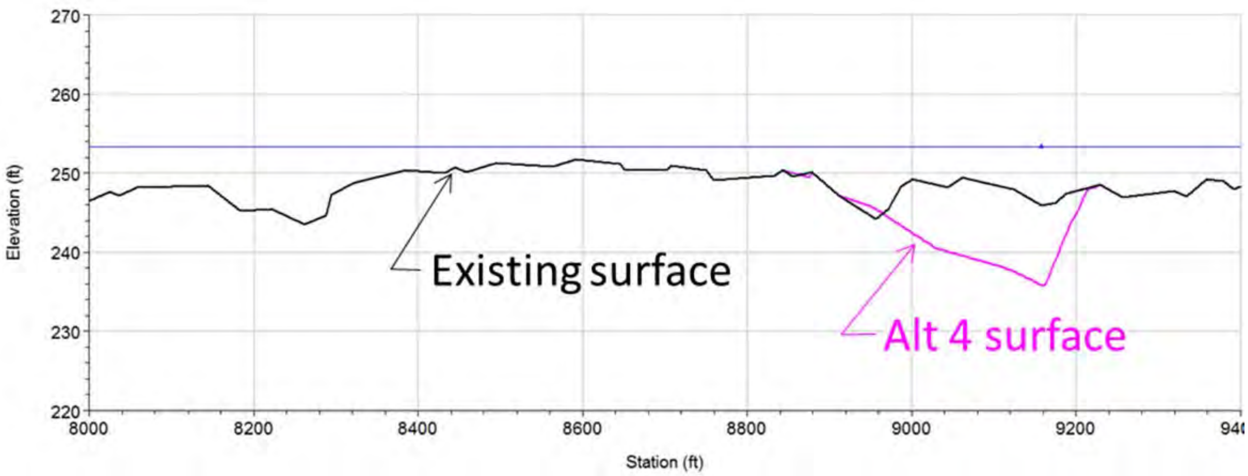

Figure 8. Representative cross-section in the floodplain area at the proposed flow split to Barnaby Slough. The proposed inlet channel (cut) shown with a pink line overlay on the existing ground surface (black line).

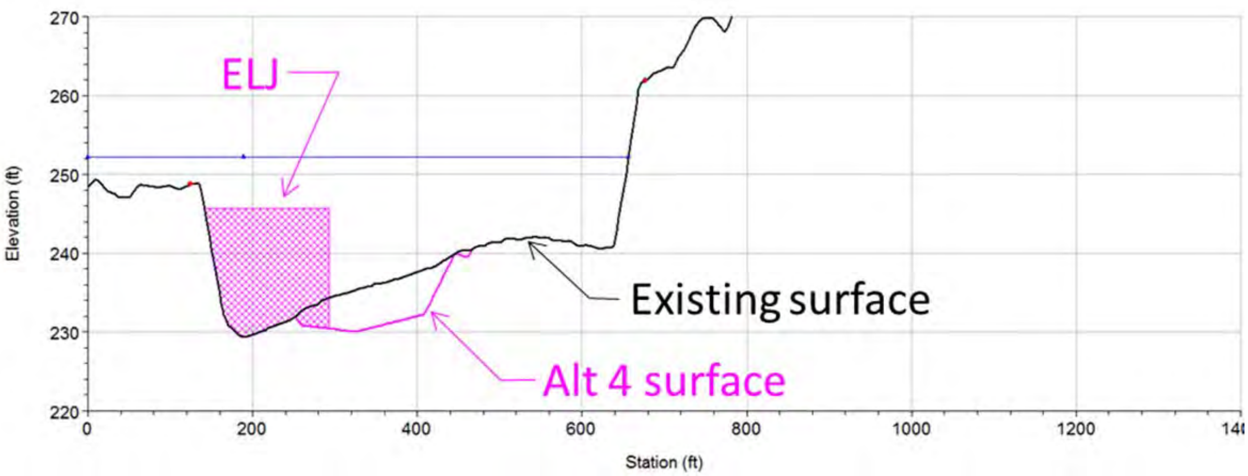

Figure 9. Representative cross-section in the existing mainstem just downstream of the proposed flow split to Barnaby Slough. The proposed ELJ (cut) shown with a pink line overlay on the existing ground surface (black line).

The flood hazard area mapped by FEMA shows the 100-year flood inundating a portion of SR20 spanning a length of approximately 3,500 feet across from, and extending downstream of, the Illabot Creek confluence (Figure 12). The highway is built upon a low terrace in this vicinity and the ground surface elevations drop slightly to the north creating a depression extending approximately 750 feet from the highway that ponds water during the 100-year flood. Figure 13 overlays a profile of the ground surface elevations along SR 20 with simulated water surface profiles and shows the deepest flow overtopping SR 20 immediately upstream of the Illabot Creek confluence. The relative difference between the water surface and the highway decreases downstream such that the highway becomes slightly elevated above the 100-year water surface. The location most affected by project actions proposed as part of Alternative 4 is shown in Figure 14. At this location (RS 22249), the road surface dips to an elevation only slightly above the 100-year flood elevation. The 0.22 foot increase under proposed (Alt 4) conditions elevates the water surface just above the roadway. Note that the area north of SR 20 is inundated by the 100-year flood under existing conditions because of overflow from upstream and the increase in water surface for Alternative 4 does not result in flooding of any substantial areas north of the highway not flooded by existing conditions.

An additional concern for potential flood impacts in the project reach involves residential property in the flood hazard area upstream of Barnaby Slough. The property includes a main residence with two outbuildings on a terrace surface adjacent to Upper Harrison Slough (Figure 12; also see maps with structure locations in Appendices A and B). Under existing conditions, the flow depth of the 100-year flood is 1.0 feet above ground surface at the location of the residence. The relative increase in water surface elevation from the proposed (Alt 4) conditions simulation is 0.3 feet at this location. Two additional outbuildings are located along a private road approximately 1,000 feet to the north (upstream) of the main residence. The flow depth of the 100-year flood is approximately 1.8 feet under existing conditions and increases by 0.2 feet under the proposed conditions simulation.

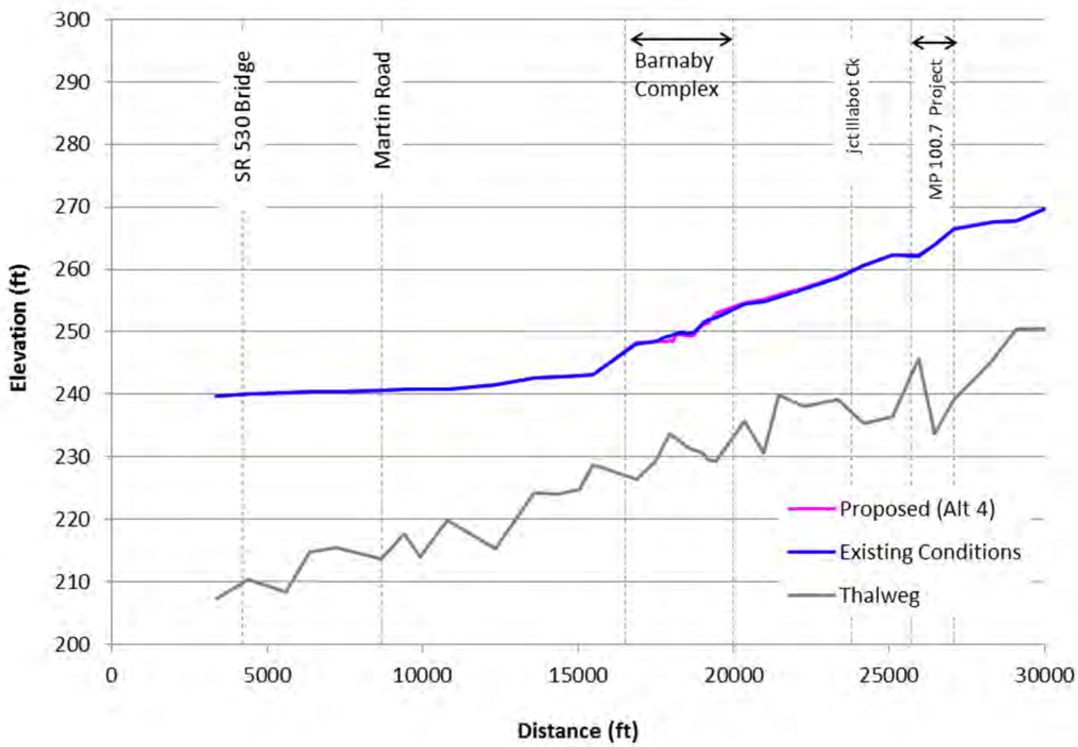

Figure 10. Water surface profiles of the 100-year recurrence interval flow for existing and proposed conditions simulated with the 1D (HEC-RAS) hydraulic model.

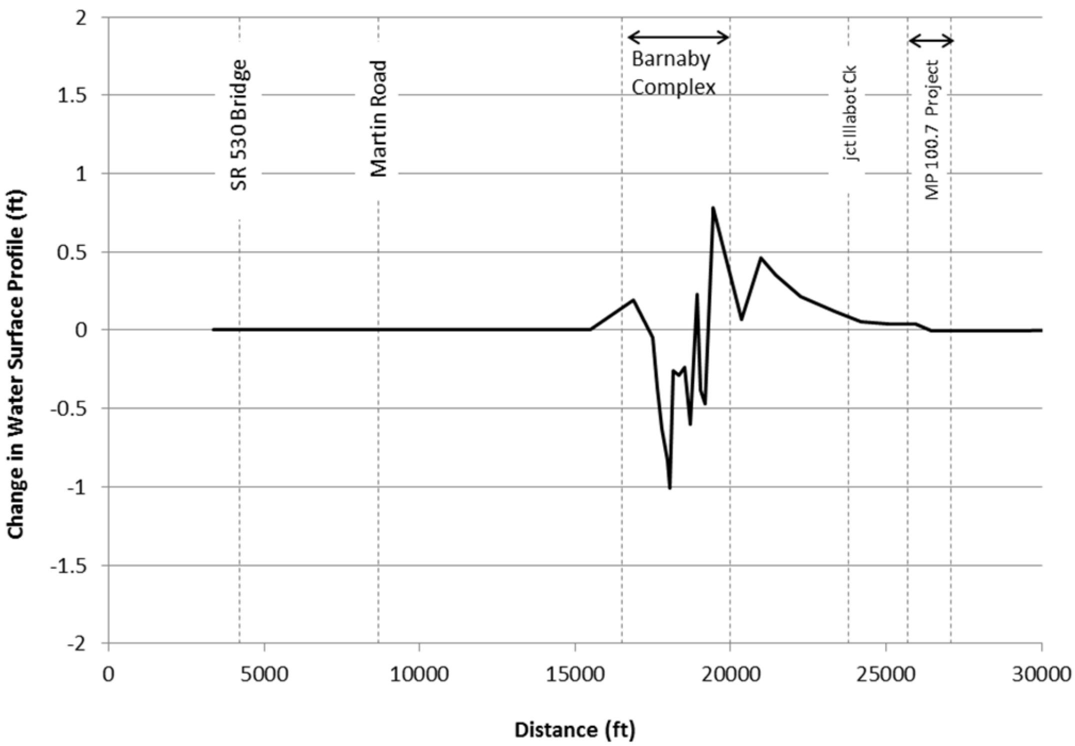

Figure 11. Profile of the resulting change in water surface (Proposed - Existing) for the 100-year recurrence interval flow.

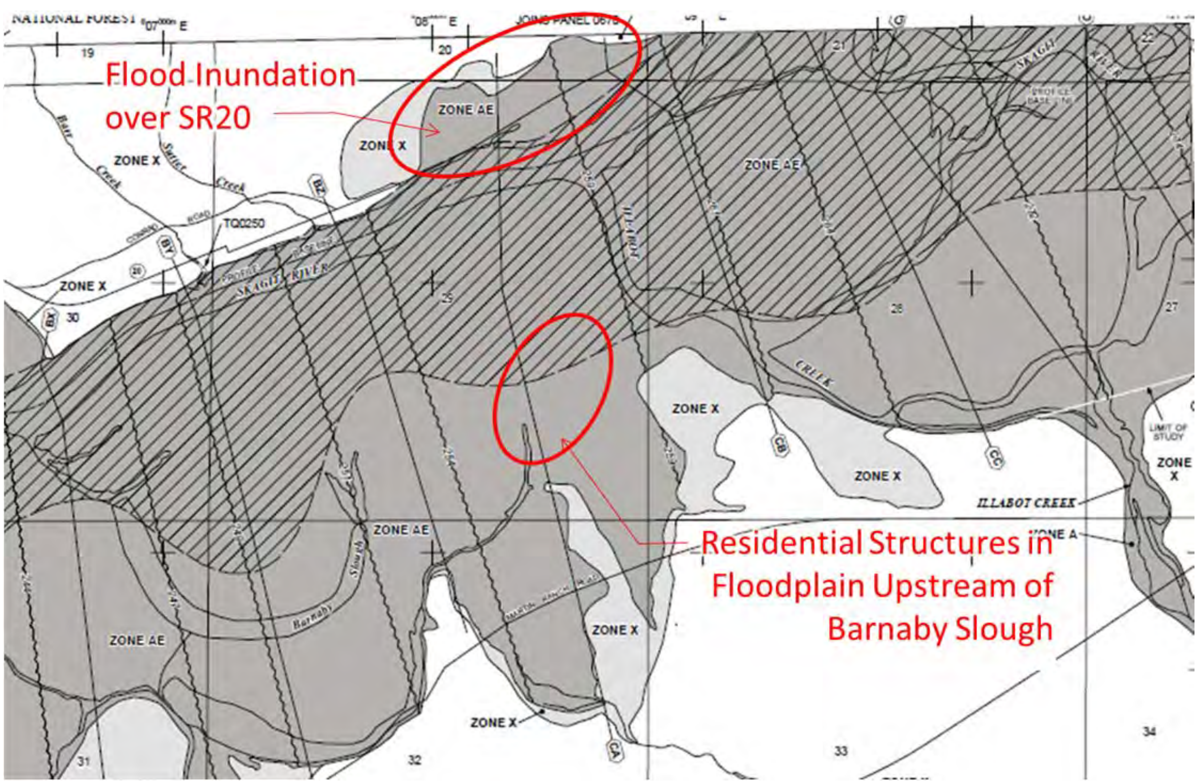

Figure 12. Excerpt of FEMA Flood Insurance Rate Map with annotations of potential flood hazard concerns upstream of the proposed project at Barnaby Slough. Full map panels are attached in Appendix C.

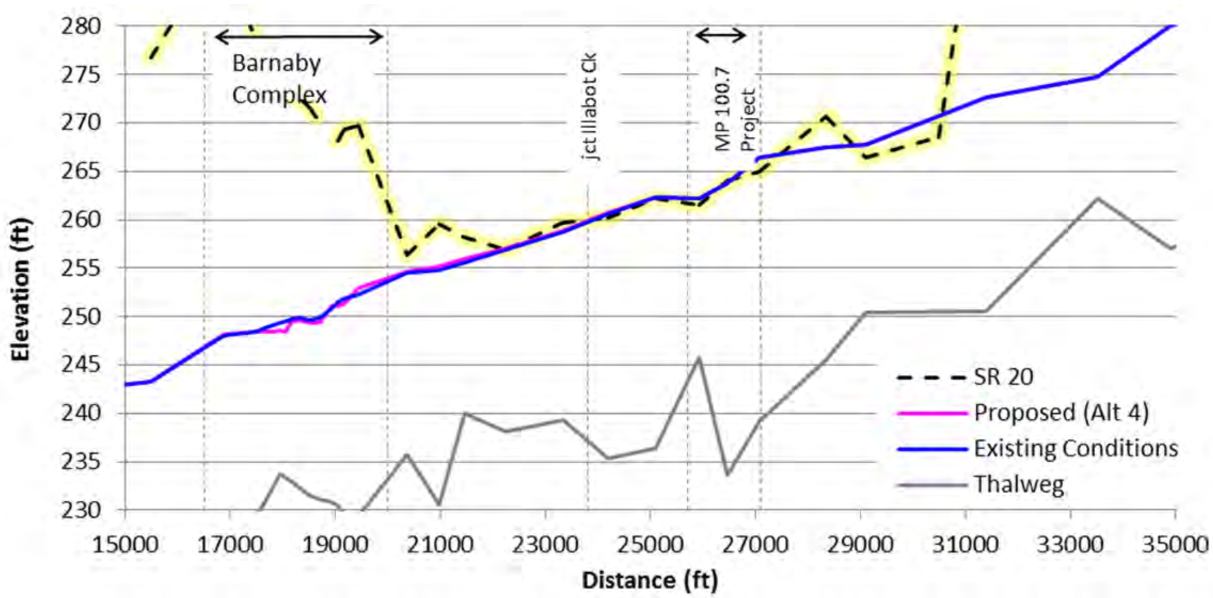

Figure 13. Profile of existing/proposed (Alt 4) water surface for the 100-year recurrence interval flow with an overlay of the ground surface along SR 20.

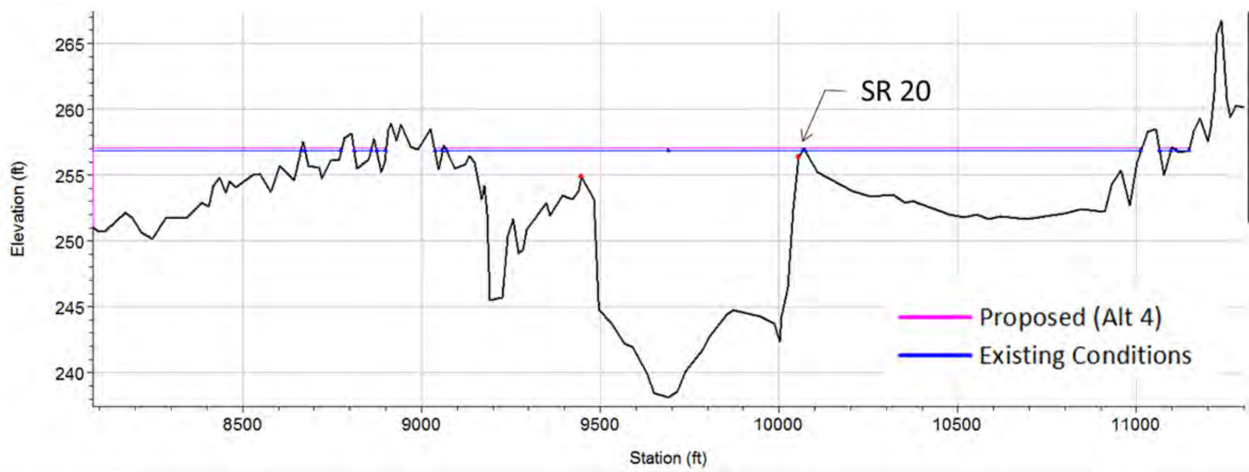

Figure 14. Cross-section approximately 2,800 feet upstream of the proposed split flow reconnecting Barnaby Slough (RS 22249). The simulation of proposed (Alt 4) conditions shows a 0.22 foot rise in the 100-year water surface elevation at this location (~RM 71.4) adding to the depth of flow overtopping SR 20.

CONCLUSIONS

NSD has prepared this evaluation for SRSC in accordance with generally accepted practices for hydrologic and hydraulic analysis to estimate water surface profiles for flood flows in the Skagit River based on existing channel/floodplain geometry and proposed changes outlined in the Habitat Restoration Alternatives Analysis (SRSC and NSD, 2014). The supplemental hydraulic analysis presented in this memorandum provides additional information to clarify anticipated upstream/downstream effects in regards to flood and erosion hazards associated with proposed actions for the Barnaby Reach Floodplain Restoration Project. Both the 1-D and 2-D model simulations described in this evaluation require simplifying assumptions to represent the natural environment and have inherent uncertainty in model results. One key assumption applied in the evaluation is that hydraulic characteristics (e.g., channel profile, cross-sectional area, and boundary roughness) of upstream and downstream characteristics remain consistent over time and only the project area is changed between existing and proposed model simulations. This assumption isolates changes at the project site and identifies potential impacts caused by proposed changes. Future model simulations could utilize mobile bed hydraulic models to better quantify changes in sediment dynamics and morphologic channel response.

Key points highlighted in the results include:

- Unsteady flow hydraulic results are a better representation of lower more frequent flood events within the project area. While reasonable for comparing alternatives, methodology associated with previously completed steady state runs resulted in an overly conservative portrayal of downstream flood risks.
- New results eliminate concerns from Alternative 4 increasing flood risk for lower more frequent and major flood events within private parcels near Martin Road. Ensuring that the flow entering the Barnaby complex exits through Lucas Slough and not False Lucas slough will increase factor of safety for downstream flood risks within private parcels near Martin Road.
- New results suggest the erosion conditions near Martin Road will remain unchanged from current conditions. Model results do show a small reduction in velocities downstream of the Barnaby Slough outlet; however, this small reduction is not expected to significantly affect channel migration rates or erosion.
- Flow obstructions from the ELJs constricting the existing mainstem channel result in a 0.8 foot increase in water surface elevation immediately upstream of the proposed inlet connection and this rise in the 100-year flood profile tapers to match existing flood elevations upstream to the bend at the upstream end of the recently constructed MP 100.7 bank protection project along SR 20.
- The rise in water surface elevation results in additional inundation of 9 acres during the 100-year flood; mostly distributed on the edges of the floodplain area over a 4,000 foot segment between Barnaby Slough (~RM 70.8) and Illabot Creek (~RM 71.6).
- The predicted upstream backwater effect increases the 100-year flood water elevations 0.22 feet at RM 71.4, increasing the depth of flow that already overtops SR 20 under existing conditions during the 100-year flood.
- The predicted upstream backwater effect from mainstem ELJs increases the 100-year flood water elevations 0.2 to 0.3 feet at structures built on private property in the floodplain area upstream of Barnaby Slough. These structures are built within the current FEMA flood hazard area and are flooded in the existing conditions simulation. There are no additional structures flooded in the proposed conditions simulation.

RECOMMENDATIONS

Results of the supplemental hydraulic analyses completed for the Barnaby Reach Habitat Restoration Alternatives Analysis are intended to inform evaluation of the project actions proposed as Alternative 4. Findings of the analysis provide support for Alternative 4 as a feasible restoration approach that addresses project objectives without increasing flood or erosion risk to downstream properties and with minimal increase in flood risk to upstream areas that can be mitigated with design refinement and/or property acquisition.

Recommendations regarding current conditions

Under existing conditions, independent of any restoration action taken, the hydraulic analysis identifies and confirms significant risks from flooding and channel migration to some residents along Martin Road. Multiple private properties are exposed to flood and erosion hazards given their location within the active floodplain and channel migration zone. Existing model results should be considered the minimum extent of flooding directly related to Skagit River flood flows and do not consider small tributary flows and drainage area that contribute to the False Lucas or Boh's slough. Aging, unmaintained, or undersized infrastructure (culverts, bridges, etc) or other factors within those drainage networks that may contribute to local flooding were not explicitly consider in this analysis. Considering existing flood risk , we recommend pursuing acquisition of at-risk properties from willing sellers regardless of which future restoration actions are taken. Properties with current flood insurance may qualify for FEMA repetitive loss programs to assist with relocation, and there are likely a number of conservation and government organizations that would be willing to support this effort.

Additionally, this evaluation verifies concerns that Martin Road is at high risk from channel migration and should be considered for partial abandonment or relocation further south. Both current channel migration trends and the high frequency of inundation suggest that a project(s) to protect or significantly reduce flood or erosion risk to Martin Road would be a major state capital project requiring significant investment of public funds. Our judgment is that efforts to restrict channel migration in this location would further impair natural processes in this dynamic sub-reach and would stand little chance of success. Relocating the road alignment away from the areas of erosion risk is likely to be the most cost effective solution to the erosion hazard at this location.

Recommendations regarding restoration actions

Whatever restoration action is chosen within the Barnaby reach proponents should consider the merit of project elements such as wood structures at targeted locations to moderate the potential for channel widening, bank erosion, and potential for channel avulsion that could adversely affect flood and erosion hazards to adjacent property. Key areas to consider for these wood structures in design might include:

- The outer bend of Barnaby Slough,
- Inlet channels to Harrison Slough and Lucas Slough,
- False Lucas Slough.

Design concepts for wood placement could include deflector structures that direct flow away from areas of potential concern and/or pile arrays that roughen the channel and trap wood creating obstructions to flow, thereby reducing migration potential. These should be explored in detail during the design phase of a restoration project.

Potential flood protection approaches such as levees or berms to protect flood-prone areas were considered but are not recommended given the structure locations within the existing floodplain areas, the engineering constraints to construct a structure that would be effective in this location, and regulatory hurdles to obtain permits for a levee. Given the likelihood of local drainage factors contributing to flooding near Martin Road, further investigation is also recommended to better understand the root causes of flooding and identify possible actions (culvert upsizing, drainage improvements, etc) that could reduce flood extents during smaller and more frequent storm events.

The analysis also indicates Alternative 4 as currently proposed has the potential to increase flood risk upstream from Barnaby Slough at locations along SR 20 that are prone to overtopping under existing conditions.. We recommend the design process refine the design criteria for proposed ELJs and the inlet connection between the mainstem channel and Barnaby Slough to minimize the backwater effect and reduce upstream flood impacts. Design criteria to be evaluated include the location, orientation, size, and amount of obstruction caused by mainstem ELJs and the width, alignment and slope of the inlet channel to Barnaby Slough. The increased upstream flood risk also impacts private property along Martin Ranch Road that are currently within 100-year FEMA floodplain. We recommend that private properties upstream of Barnaby Slough and within the floodplain on the south side of the valley that are currently for sale be acquired and put into conservation ownership to protect riparian processes and floodplain habitats. If these properties are acquired there is also potential to create a secondary inlet and connection to the Illabot Creek confluence further improving habitat conditions within the Barnaby complex.

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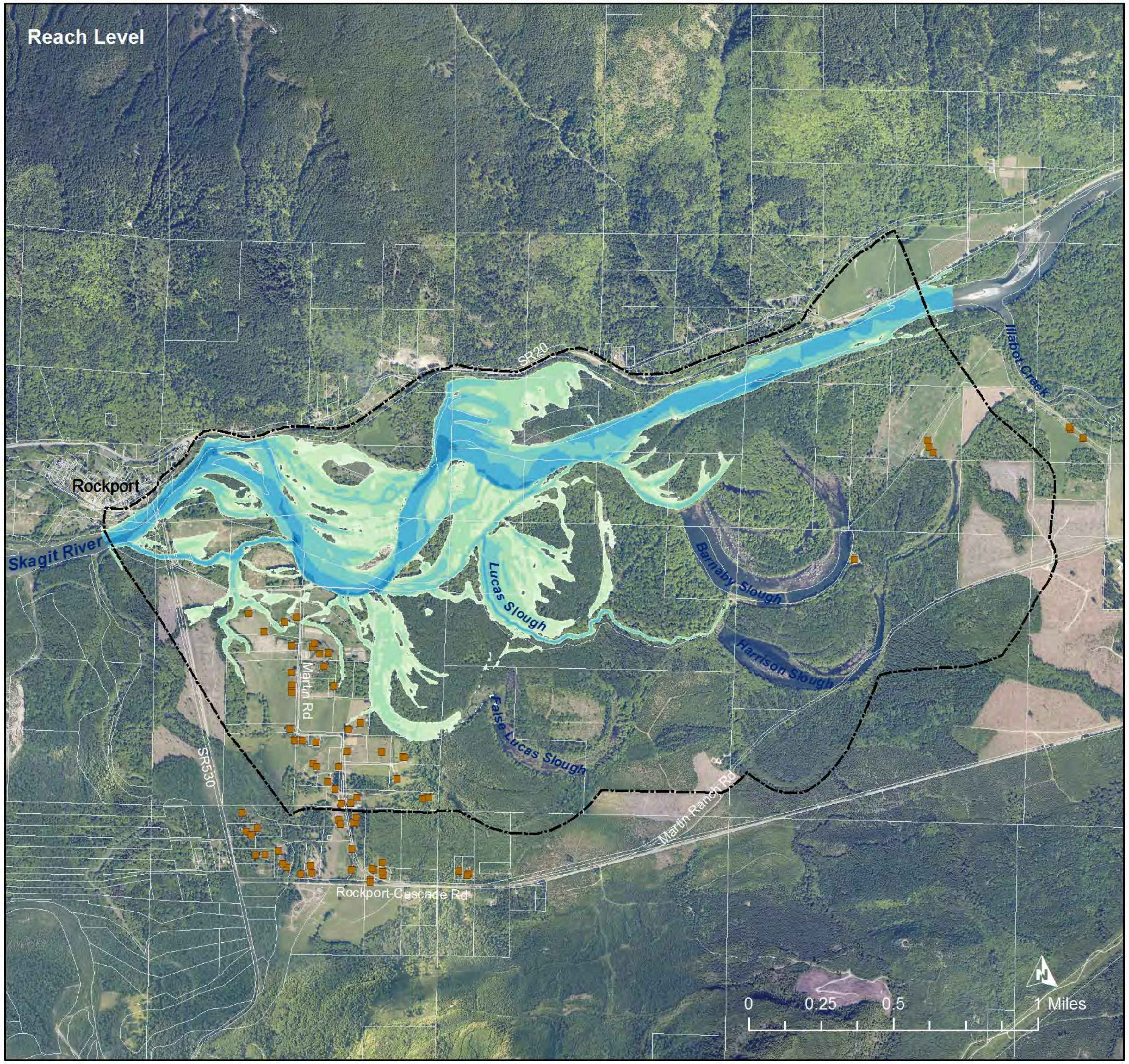
APPENDIX A: 2D HYDRAULIC MODEL RESULTS

1. Existing Conditions, 2-Year Flow, Maximum Depth
2. Existing and Alternative 4, 2-Year Flow, Maximum Depth Results and Differences
3. Existing Conditions, 2-Year Flow, Maximum Velocity
4. Existing and Alternative 4, 2-Year Flow, Maximum Velocity Results and Differences
5. 2-Year Flow, Depth Difference (Alternative 4 – Existing)
6. 2-Year Flow, Velocity Difference (Alternative 4 – Existing)



Barnaby Reach Unsteady State Model - Existing 2-YR Flow Maximum Depth

- Structures (homes, barns, garages)
- Boundary
- Skagit Co Parcels (2014)

Maximum Depth (ft)

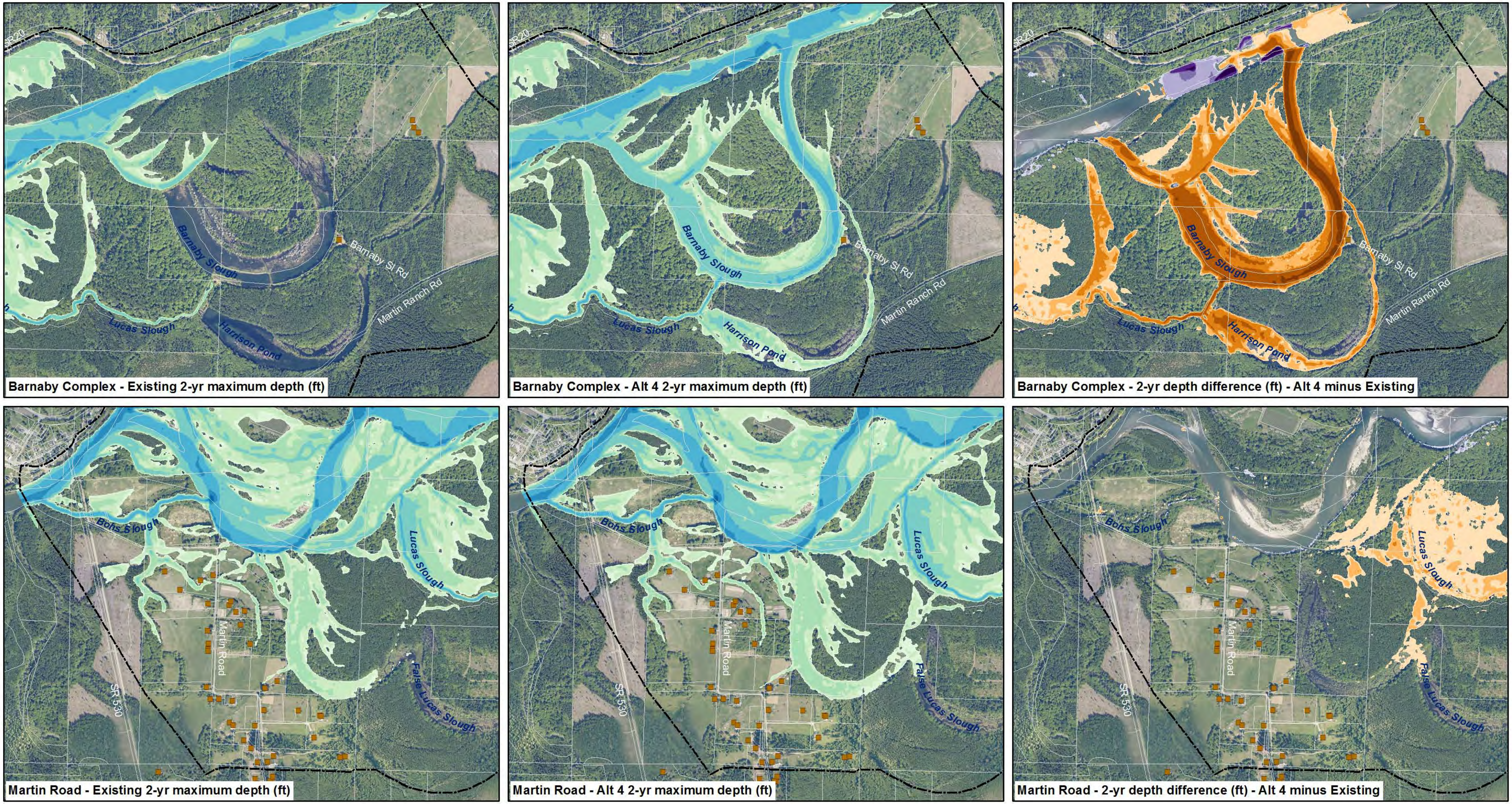
0 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, 8 - 14, 14 - 22, 22 - 30, > 30

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

Prepared by Kate Ramsden, 12/16/14

Natural Systems Design

Skagit River System Cooperative



Barnaby Reach Unsteady State Model - Existing and Alt 4 2-YR Flow Maximum Depth Results and Differences

Structures (homes, barns, garages)

Boundary

Skagit Co Parcels (2014)

Maximum Depth (ft)

0 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, 8 - 14, 14 - 22, 22 - 30, > 30

Depth Difference (ft): Alt 4 minus Existing

< -8, -8 - -4, -4 - -2, -2 - -1, -1 - -0.5, -0.5 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, > 8

N

0 1,000 2,000 Feet

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

Prepared by Kate Ramsden, 12/16/14

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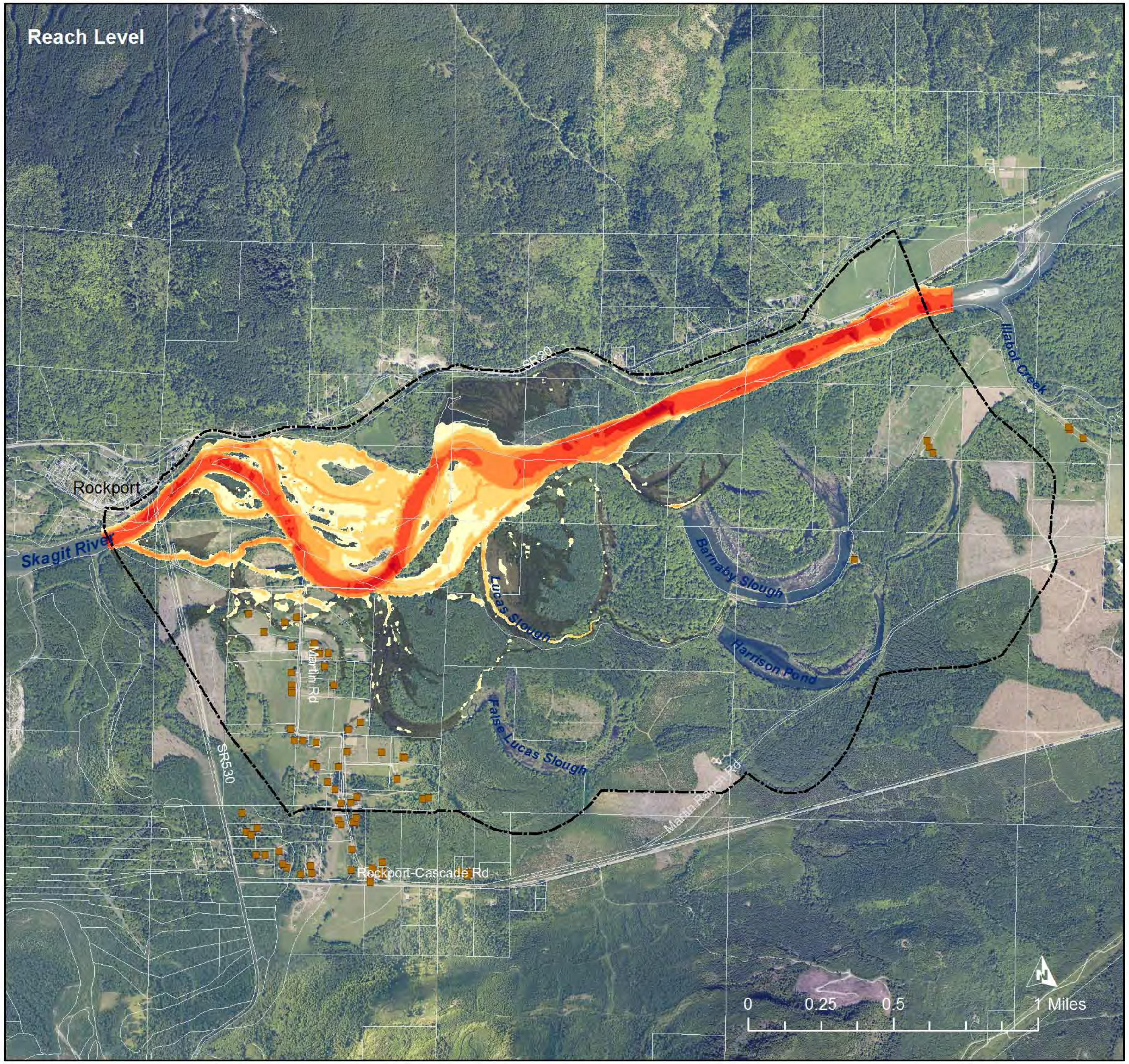

Barnaby Reach Unsteady State Model - Existing 2-YR Flow Maximum Velocity

- Structures (homes, barns, garages)
- Boundary
- Skagit Co Parcels (2014)

Maximum Velocity (ft/s)

0 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, 8 - 12, 12 - 16, 16 - 20, > 20

Area inundated but without significant flow (<0.5 ft/s)

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

Prepared by Kate Ramsden, 12/16/14

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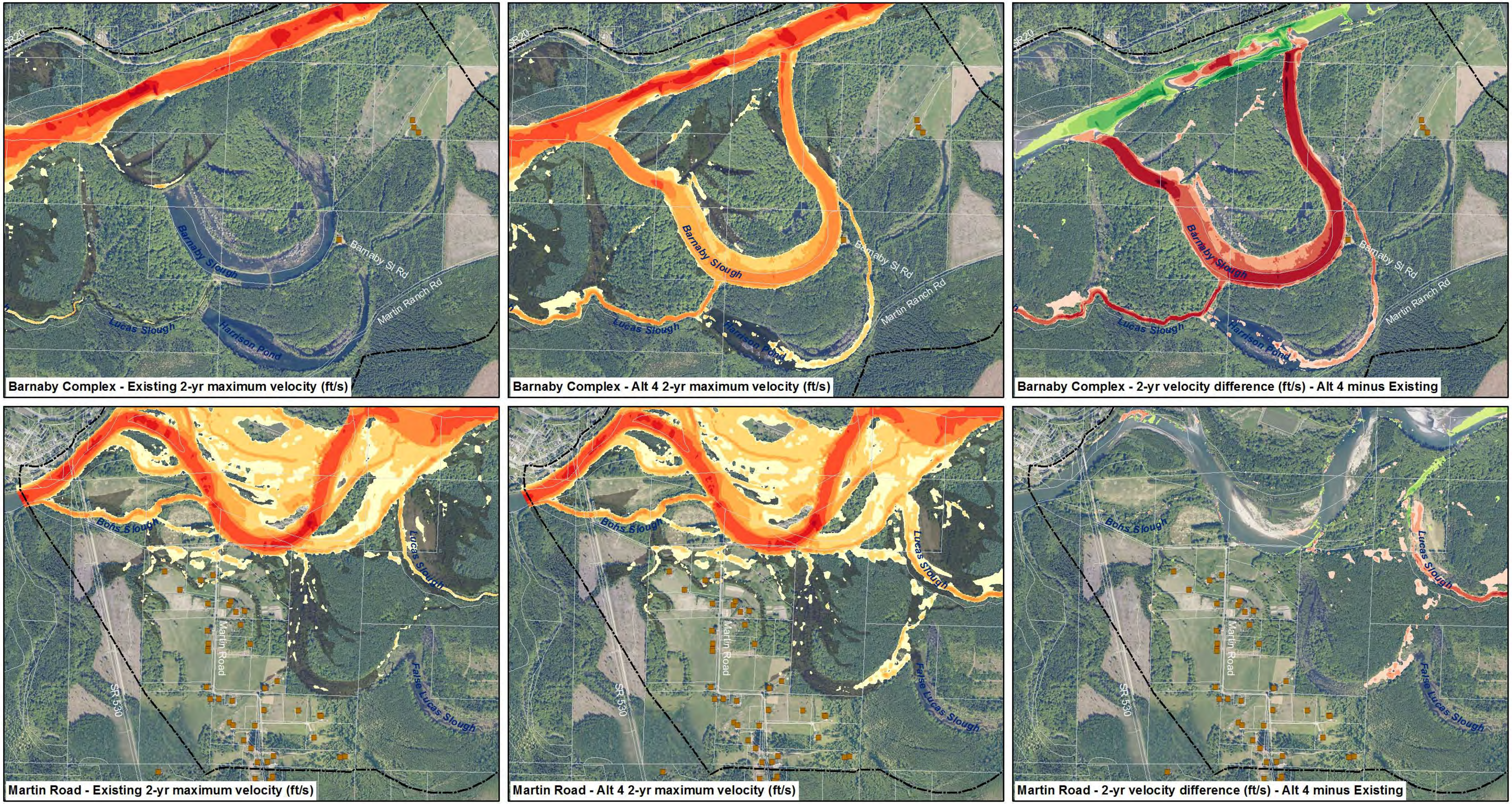

Barnaby Reach Unsteady State Model - Existing and Alt 4 2-YR Flow Maximum Velocity Results and Differences

Structures (homes, barns, garages)
Boundary
Skagit Co Parcels (2014)

Maximum Velocity (ft/s)
0 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, 8 - 12, 12 - 16, 16 - 20, > 20

Area inundated but without significant flow (<0.5 ft/s)

Velocity Difference (ft/s): Alt 4 minus Existing
< -8, -8 - -4, -4 - -2, -2 - -1, -1 - -0.5, -0.5 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, > 8

0 1,000 2,000 Feet

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

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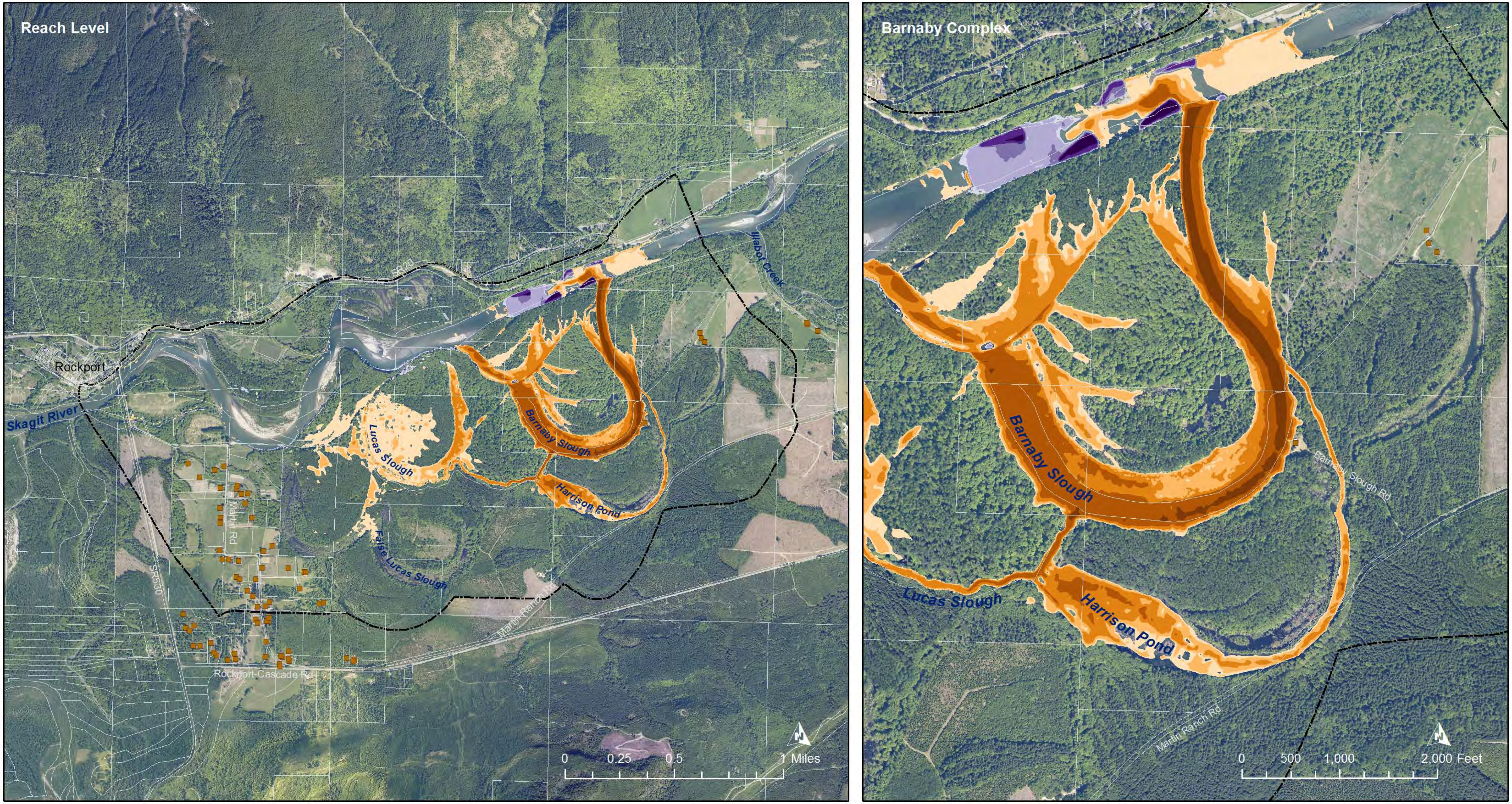

Barnaby Reach Unsteady State Model - 2-YR Depth Difference [Alt 4 minus Existing]

Structures (homes, barns, garages)
Skagit Co Parcels (2014)
Boundary

Depth Difference (ft): Alt 4 minus Existing

<-8, -8 - -4, -4 - -2, -2 - -1, -1 - -0.5, -0.5 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, >8

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

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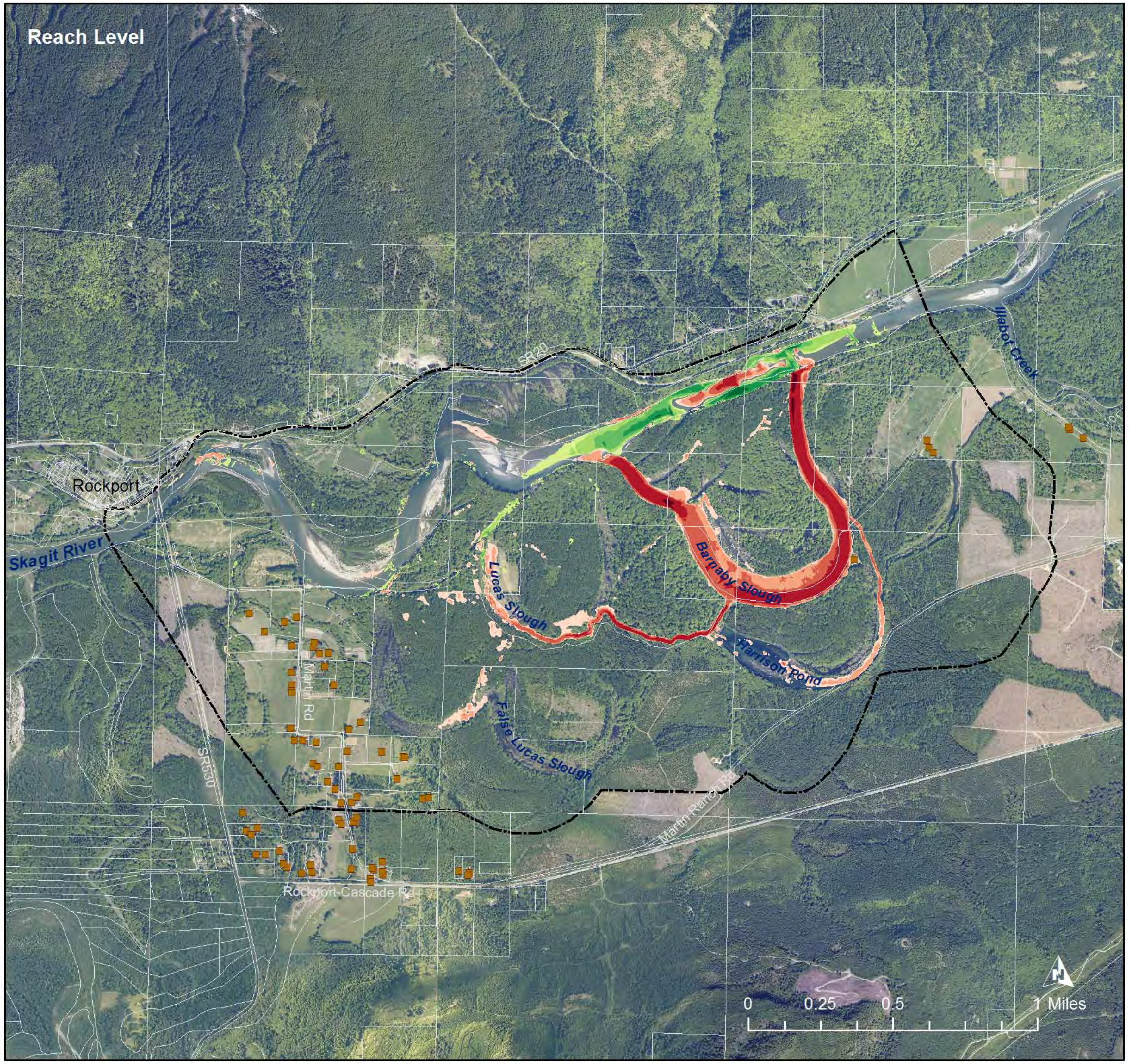

Barnaby Reach Unsteady State Model - 2-YR Velocity Difference [Alt 4 minus Existing]

- Structures (homes, barns, garages)
- Skagit Co Parcels (2014)
- Boundary

Velocity Difference (ft/s): Alt 4 minus Existing

<-8, -8 - -4, -4 - -2, -2 - -1, -1 - -0.5, -0.5 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, >8

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

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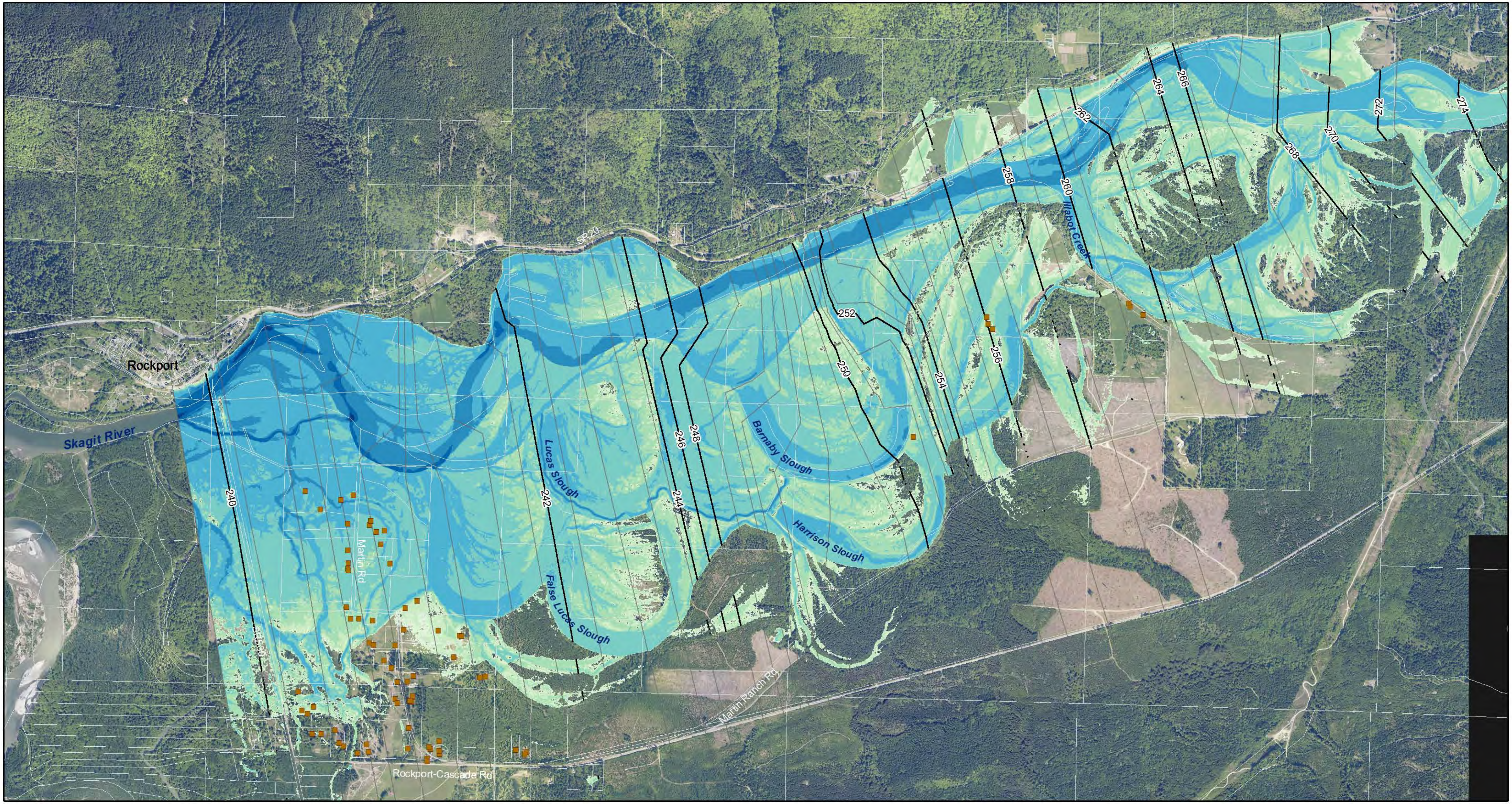
APPENDIX B: 1D HYDRAULIC MODEL RESULTS

1. Existing Conditions 100-Year Flow Depth
2. Proposed (Alternative 4) Conditions 100-Year Flow Depth
3. Relative Difference in 100-Year Flow Depth (ALT 4 – Existing)



Barnaby Reach 1-Dimensional Model - Existing 100-YR Flow Depth

Structures (homes, barns, garages)
Skagit Co Parcels (2014)
Water Surface Elevation
HEC-RAS Cross Sections

Depth (ft)
0 - 0.5
0.5 - 1
1 - 2
2 - 4
4 - 8
8 - 14
14 - 22
22 - 30
> 30

0 1,000 2,000 Feet

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

Prepared by Kate Ramsden, 12/18/14

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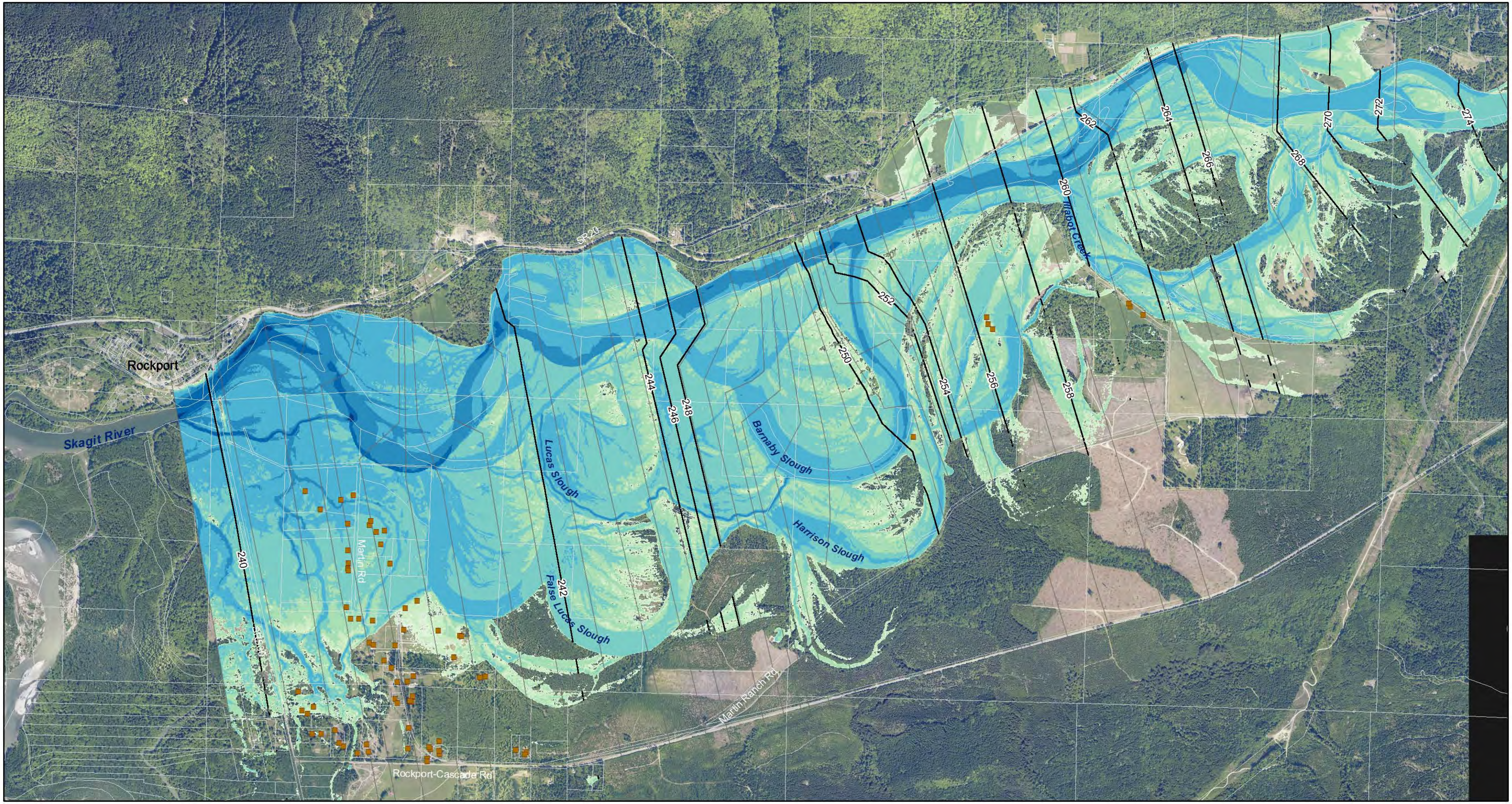

Barnaby Reach 1-Dimensional Model - Alt 4 100-YR Flow Depth

Structures (homes, barns, garages)
Skagit Co Parcels (2014)
Water Surface Elevation
HEC-RAS Cross Sections

Depth (ft)

0 - 0.5, 0.5 - 1, 1 - 2, 2 - 4, 4 - 8, 8 - 14, 14 - 22, 22 - 30, > 30

0 1,000 2,000 Feet

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

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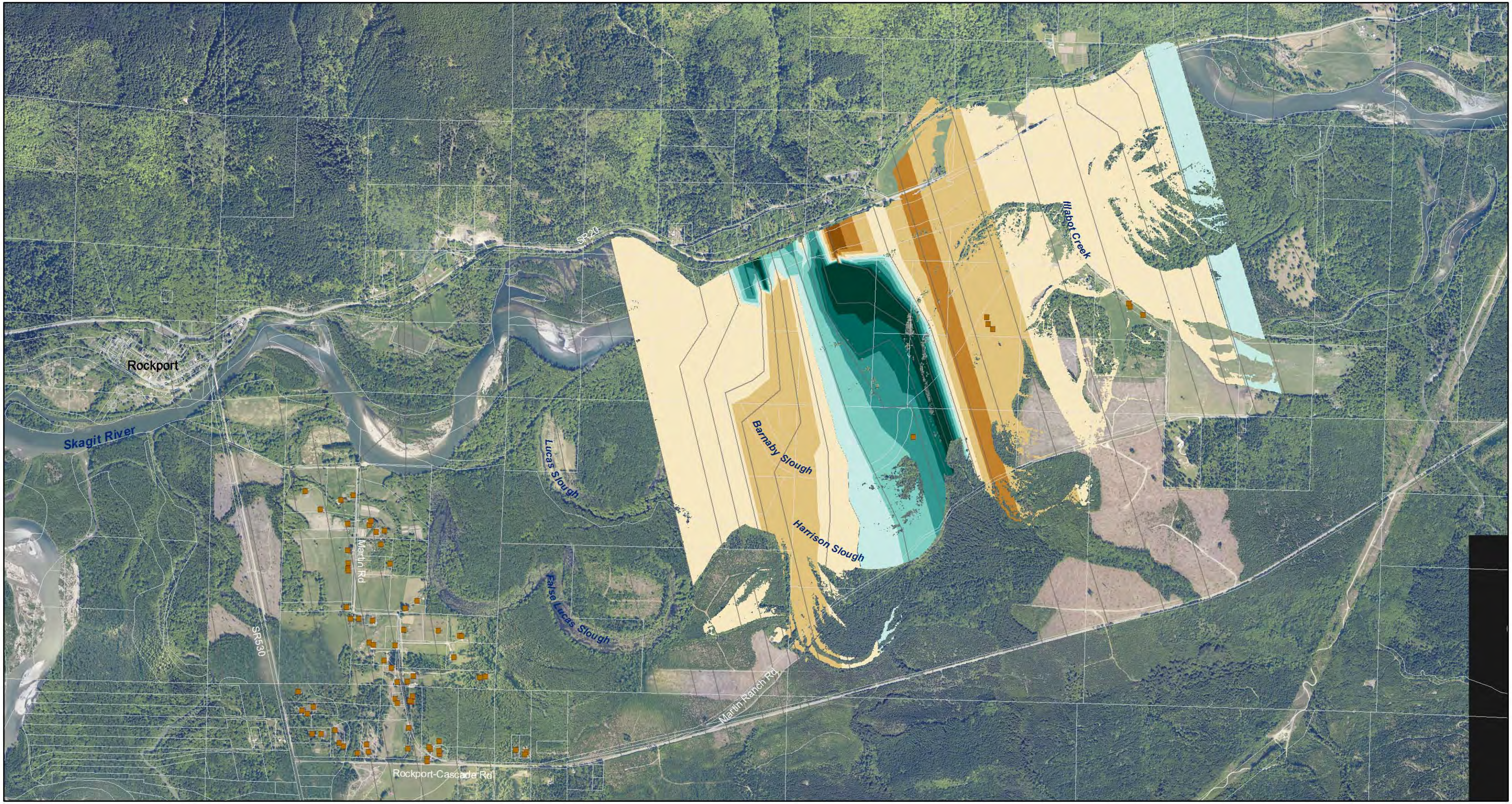

Barnaby Reach 1-Dimensional Model - Difference in 100-YR Flow Depth [Alt 4 minus Existing]

- Structures (homes, barns, garages)
- HEC-RAS Cross Sections
- Skagit Co Parcels (2014)

Depth Difference (ft)

-1.01 - -0.8 | -0.8 - -0.6 | -0.6 - -0.4 | -0.4 - -0.2 | -0.2 - -0.001 | -0.001 - 0.001 | 0.001 - 0.2 | 0.2 - 0.4 | 0.4 - 0.6 | 0.6 - 0.8

0 1,000 2,000 Feet

Data Sources:
Model Results: Natural Systems Design
2013 Air Photo: Skagit County/Pictometry

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APPENDIX C: FEMA FLOOD INSURANCE RATE MAPS

1. Map Index to FEMA Flood Insurance Rate Maps for Skagit County
2. Map Number 53057C1105E
3. Map Number 53057C1110E
4. Map Number 53057C0670E

Maps excerpted from the Preliminary Flood Insurance Study for Skagit County
http://www.skagitcounty.net/Departments/PlanningAndPermit/FEMAfloodstudy.htm

FIRM Panel Dates For Printed Panels of Skagit County, WA And Incorporated Areas					
Panel	Effective Date	Panel	Effective Date	Panel	Effective Date
0025 E		0625 E		0962 E	
0075 E		0636 E		0963 E	
0100 E		0640 E		0964 E	
0125 E		0645 E		0966 E	
0150 E		0650 E		0967 E	
0175 E		0670 E		0968 E	
0200 E		0685 E		0976 E	
0225 E		0690 E		0977 E	
0300 E		0695 E		0980 E	
0440 E		0715 E		0985 E	
0445 E		0725 E		0990 E	
0450 E		0750 E		0995 E	
0465 E		0775 E		1005 E	
0475 E		0880 E		1050 E	
0480 E		0885 E		1085 E	
0485 E		0900 E		1100 E	
0490 E		0905 E		1105 E	
0495 E		0908 E		1110 E	
0505 E		0909 E		1115 E	
0510 E		0910 E		1120 E	
0515 E		0912 E		1130 E	
0519 E		0915 E		1150 E	
0520 E		0916 E		1175 E	
0530 E		0917 E		1200 E	
0538 E		0918 E		1257 E	
0539 E		0919 E		1275 E	
0540 E		0930 E		1300 E	
0545 E		0935 E		1325 E	
0564 E		0936 E		1350 E	
0565 E		0938 E		1375 E	
0568 E		0940 E		1400 E	
0570 E		0945 E		1455 E	
0575 E		0951 E		1460 E	
0588 E		0952 E		1470 E	
0589 E		0953 E		1480 E	
0595 E		0954 E		1485 E	
0600 E		0956 E		1490 E	
0615 E		0957 E		1495 E	
0617 E		0958 E		1525 E	
0619 E		0959 E		1550 E	
0620 E		0961 E		1575 E	

NOTE TO USER

Future revisions to this FIRM Index will only be issued to communities that are located on FIRM panels being revised. This FIRM Index therefore remains valid for FIRM panels dated or earlier. Please refer to the "MOST RECENT FIRM PANEL DATE" column in the Listing of Communities table to determine the most recent FIRM Index date for each community.

LISTING OF COMMUNITIES

COMMUNITY NAME	COMMUNITY NUMBER	LOCATED ON PANEL(S)	INITIAL NFIP MAP DATE	INITIAL FIRM DATE	MOST RECENT FIRM PANEL DATE
ANACORTES, CITY OF	530317	0440, 0445, 0465, 0880, 0885, 0905, 0908, 0909	October 25, 1974	September 17, 2003	
BURLINGTON, CITY OF	530153	0951, 0952, 0953, 0954, 0956, 0958	May 24, 1974	January 3, 1985	
CONCRETE, TOWN OF	530154	0617, 0619, 0636, 0640	May 17, 1974	August 2, 1982	
HAMILTON, TOWN OF	530155	0570, 0588, 0589, 0600	June 27, 1975	December 1, 1981	
LA CONNER, TOWN OF	530156	0919, 0938	May 24, 1974	December 18, 1984	
LYMAN, TOWN OF	530157	0564, 0568	November 15, 1974	July 19, 1982	
MOUNT VERNON, CITY OF	530158	0953, 0954, 0958, 0961, 0962, 0963, 0964, 0966, 0967, 0968, 0969[1]	May 17, 1974	January 3, 1985	
SAUK-SUIATTLE INDIAN TRIBE	530340	1460	October 25, 1974	September 29, 1989	
SEDRO-WOOLLEY, CITY OF	530159	0519, 0538, 0539, 0957, 0976, 0977	May 24, 1974	July 5, 1982	
SKAGIT COUNTY (UNINCORPORATED AREAS)	530151	0025, 0050[1], 0075, 0100, 0125, 0150, 0175, 0200, 0225, 0250[1], 0275[1], 0300, 0325[1], 0350[1], 0375[1], 0400[1], 0425[1], 0440, 0445, 0450, 0465, 0475, 0480, 0485, 0490, 0495, 0505, 0510, 0515, 0519, 0520, 0530, 0535[1], 0538, 0539, 0540, 0545, 0564, 0565, 0568, 0570, 0575, 0588, 0589, 0595, 0600, 0615, 0617, 0619, 0620, 0625, 0636, 0640, 0645, 0650, 0670, 0675[1], 0680[1], 0685, 0690, 0695, 0715, 0725, 0750, 0775, 0800[1], 0825[1], 0850[1], 0875[1], 0880, 0885, 0900, 0905, 0908, 0909, 0910, 0912, 0915, 0916, 0917, 0918, 0919, 0930, 0935, 0936, 0938, 0940, 0945, 0951, 0952, 0953, 0954, 0956, 0957, 0958, 0959, 0961, 0962, 0963, 0964, 0966, 0967, 0968, 0969[1], 0976, 0977, 0980, 0985, 0990, 0995, 1005, 1025[1], 1050, 1075[1], 1085, 1100, 1105, 1110, 1115, 1120, 1130, 1150, 1175, 1200, 1225[1], 1250[1], 1257, 1275, 1300, 1325, 1350, 1375, 1400, 1425[1], 1450[1], 1455, 1460, 1465[1], 1470, 1480, 1485, 1490, 1495, 1525, 1550, 1575	October 25, 1974	January 3, 1985	
SWINOMISH INDIAN TRIBAL COMMUNITY	530222	0908, 0909, 0912, 0916, 0917, 0918, 0919, 0936, 0938, 1257			
*UPPER SKAGIT INDIAN TRIBE	530013	0540, 0545			

*Non-floodprone
[1]Panel Not Printed

ELEVATION DATUM

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same vertical datum. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, MD 20910-3282
(301) 713-3242

BASE MAP

Base map data was provided by Skagit County GIS. It was created from available public records and existing map sources. Road centerlines were derived from orthophotos as well as from Skagit County GPS information.

NOTE TO USERS

FEMA maintains information about map features, such as street locations and names, in or near designated flood hazard areas. Requests to revise information in or near designated flood hazard areas may be provided to FEMA during the community review period, at the final Consultation Coordination Officer's meeting, or during the statutory 90-day appeal period. Approved requests for changes will be shown on the final printed FIRM.

MAP DATES

This FIRM Index displays the map date for each FIRM panel at the time that this Index was printed. Because this Index may not be distributed to unaffected communities in subsequent revisions, users may determine the current map date for each FIRM panel by visiting the FEMA Map Service Center website at http://msc.fema.gov or by calling the Map Service Center at 1-800-358-9616.

Communities annexing land on adjacent FIRM panels must obtain a current copy of the adjacent panel as well as the current FIRM Index. These may be ordered directly from the Map Service Center at the number listed above.

MAP REPOSITORIES

(Maps available for reference only, not for distribution.)

ANACORTES, CITY OF:
City Hall
904 6th Street
Anacortes, Washington 98221

BURLINGTON, CITY OF:
City Hall
833 South Spruce Street
Burlington, Washington 98233

CONCRETE, TOWN OF:
Town Hall
45672 Main Street
Concrete, Washington 98237

HAMILTON, TOWN OF:
Town Hall
584 Maple Street
Hamilton, Washington 98255

LA CONNER, TOWN OF:
Town Hall
204 Douglas Street
La Conner, Washington 98257

LYMAN, TOWN OF:
Town Hall
8224 South Main Street
Lyman, Washington 98263

MOUNT VERNON, CITY OF:
City Hall
910 Cleveland Avenue
Mount Vernon, Washington 98273

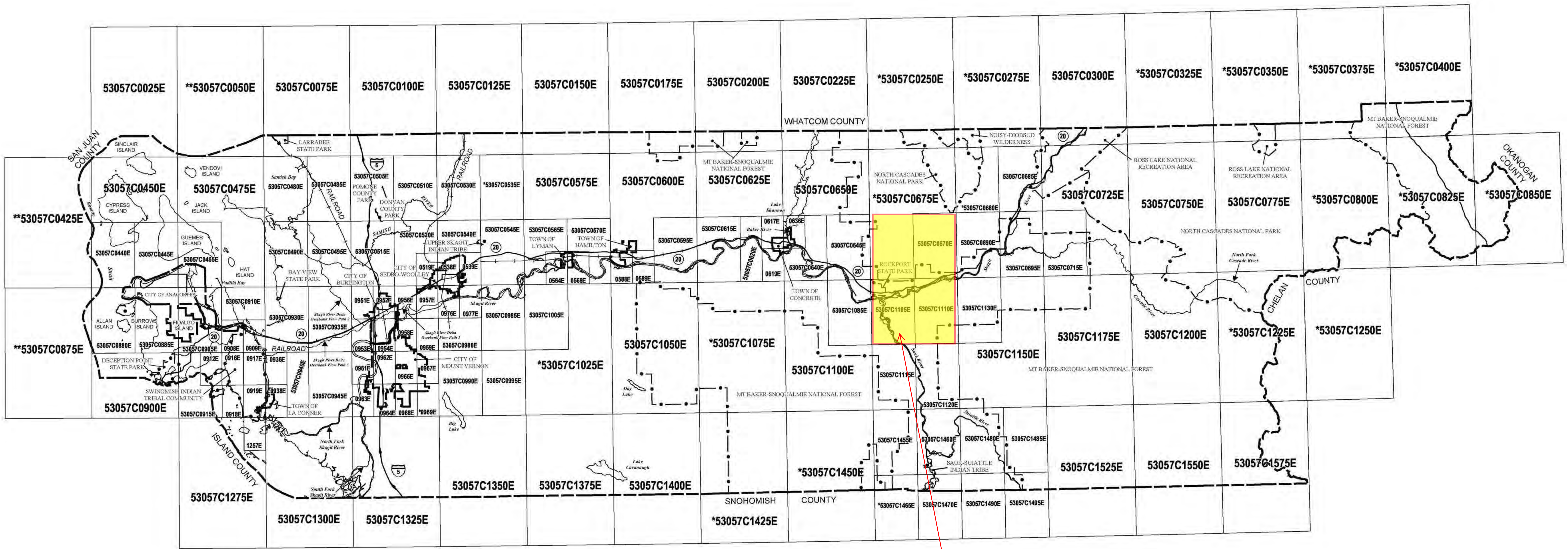
SAUK-SUIATTLE INDIAN TRIBE:
Map Repository
5318 Chief Brown Lane
Darrington, Washington 98241

SEDRO-WOOLLEY, CITY OF:
City Hall
325 Metcalf Street
Sedro-Woolley, Washington 98284

SKAGIT COUNTY (UNINCORPORATED AREAS):
Skagit County Public Works
1800 Continental Place
Mount Vernon, Washington 98273

SWINOMISH INDIAN TRIBAL COMMUNITY:
Map Repository
11404 Moorage Way
La Conner, Washington 98257

UPPER SKAGIT INDIAN TRIBE
25944 Community Plaza Way
Sedro-Woolley, Washington 98284



*PANEL NOT PRINTED - ALL ZONE X
**PANEL NOT PRINTED - ALL ZONE VE (EL13)

Map Panels Exerpted in this Appendix

MAP INDEX

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

FIRM

FLOOD INSURANCE RATE MAP

SKAGIT COUNTY, WASHINGTON

AND INCORPORATED AREAS

(SEE LISTING OF COMMUNITIES TABLE)

MAP INDEX

PANELS PRINTED: 25, 75, 100, 125, 150, 175, 200, 225, 300, 440, 445, 450, 465, 475, 480, 485, 490, 495, 505, 510, 515, 519, 520, 530, 538, 539, 540, 545, 564, 565, 568, 570, 575, 588, 589, 595, 600, 615, 617, 619, 620, 625, 636, 640, 645, 650, 670, 685, 690, 695, 715, 725, 750, 775, 880, 885, 900, 905, 908, 909, 910, 912, 915, 916, 917, 918, 919, 930, 935, 936, 938, 940, 945, 951, 952, 953, 954, 956, 957, 958, 959, 961, 962, 963, 964, 966, 967, 968, 976, 977, 980, 985, 990, 995, 1005, 1050, 1085, 1100, 1105, 1110, 1115, 1120, 1130, 1150, 1175, 1200, 1257, 1275, 1300, 1325, 1350, 1375, 1400, 1455, 1460, 1470, 1480, 1485, 1490, 1495, 1525, 1550, 1575

MAP NUMBER 53057CIND0A

EFFECTIVE DATE

Federal Emergency Management Agency

NOTES TO USERS

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Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures.** Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 10. The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

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1315 East-West Highway
Silver Spring, MD 20910-3282

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242,** or visit its website at http://www.ngs.noaa.gov/.

Base map data was provided by Skagit County GIS. It was created from available public records and existing map sources dated 2001. Road centerlines were derived from orthophotos dated 2001 and 2006 as well as from Skagit County GPS information.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables *in the Flood Insurance Study report (which contains authoritative hydraulic data*) may reflect stream channel distances that differ from what is shown on this map.

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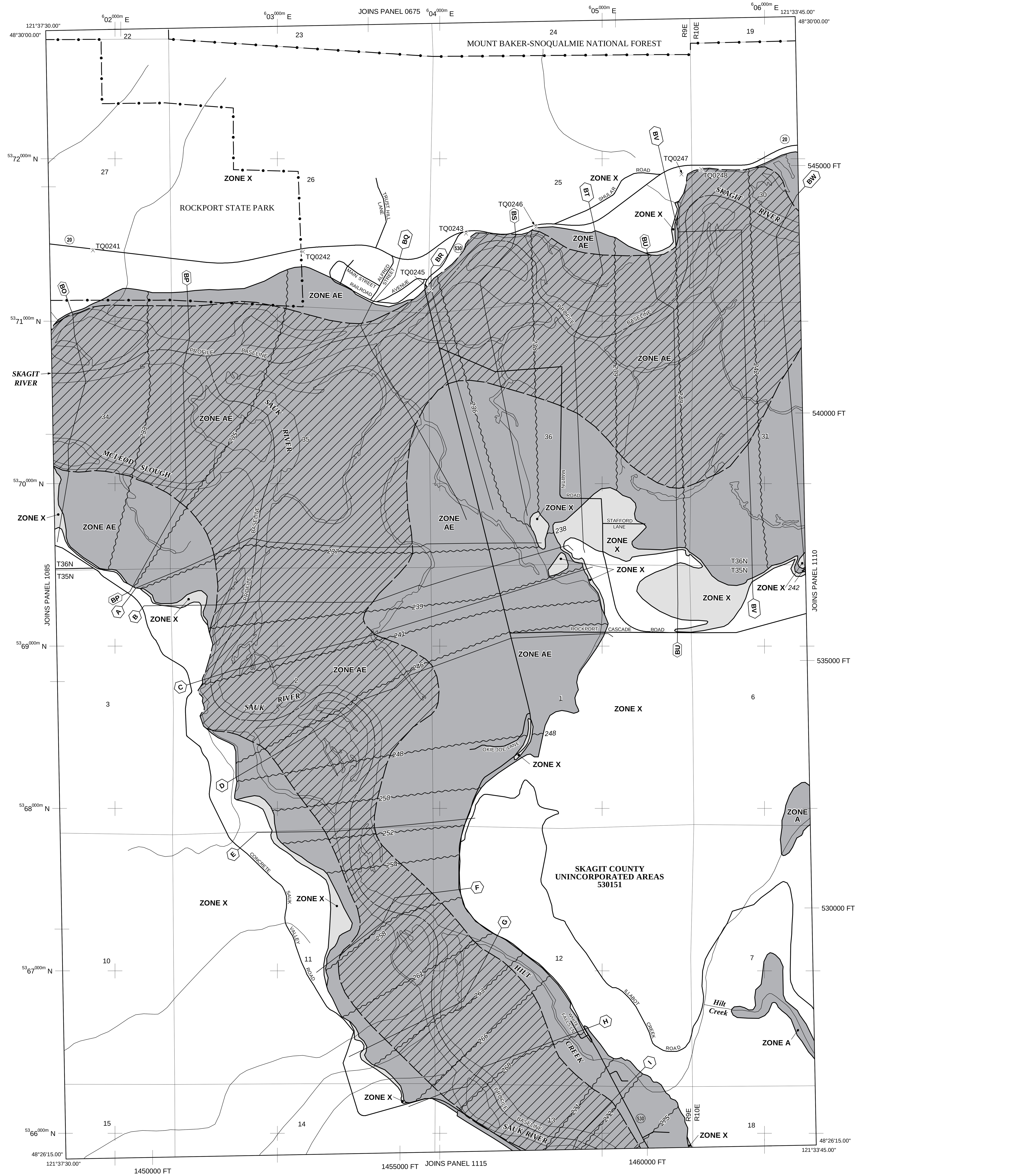
Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

Contact the **FEMA Map Service Center** at 1-800-358-9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, *a Flood Insurance Study report*, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1-800-358-9620 and its website at http://www.msc.fema.gov/.

If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1-877-FEMA MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/.

The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the FIS report. As a result of improved topographic data, the profile baseline, in some cases, may deviate significantly from the channel centerline or appear outside the SFHA.



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

Floodplain boundary

Floodway boundary

Zone D boundary

CBRS and OPA boundary

Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

A — A	Cross section line
23 - - - - 23	Transect line
97°07'30", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
$^{42}75^{000m}$N	1000-meter Universal Transverse Mercator grid ticks, zone 10
6000000 FT	5000-foot grid ticks: Washington State Plane coordinate system, north zone (FIPSZONE 4601), Lambert Conformal Conic
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

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N

MAP SCALE 1" = 1000'

500 0 1000 2000 FEET

300 0 300 600 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1105E

FIRM
FLOOD INSURANCE RATE MAP
SKAGIT COUNTY, WASHINGTON
AND INCORPORATED AREAS

PANEL 1105 OF 1575
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
SKAGIT COUNTY	530151	1105	E

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
53057C1105E

EFFECTIVE DATE

U.S. DEPARTMENT OF HOMELAND SECURITY

Federal Emergency Management Agency

NOTES TO USERS

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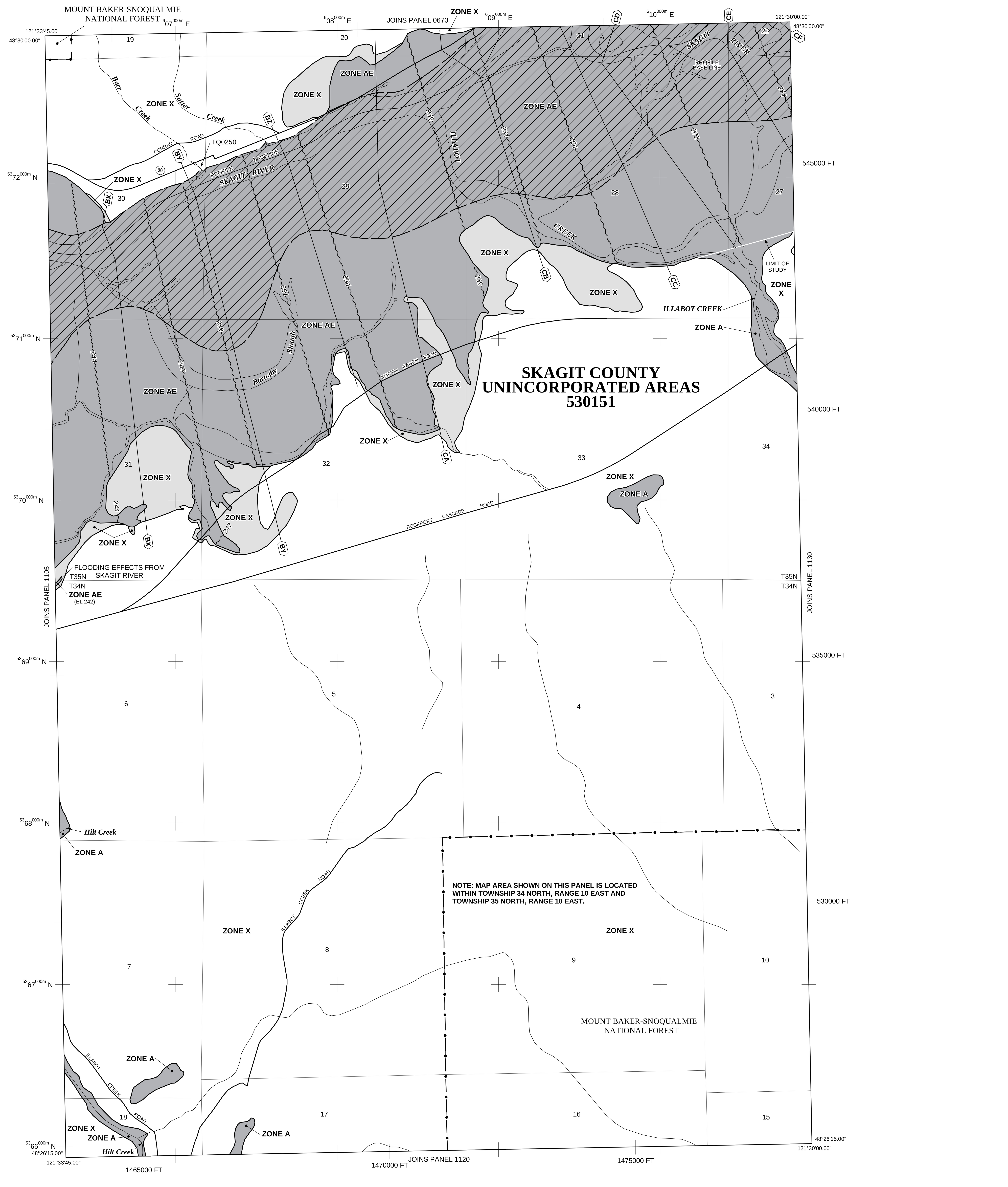

LEGEND

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513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

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(23)- - - - - - - -(23)	Transect line
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6000000 FT	5000-foot grid ticks: Washington State Plane coordinate system, north zone (FIPSZONE 4601), Lambert Conformal Conic
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
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MAP SCALE 1" = 1000'

500 0 1000 2000 FEET
300 0 300 600 METERS
0.99 in

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1110E

FIRM
FLOOD INSURANCE RATE MAP

SKAGIT COUNTY, WASHINGTON
AND INCORPORATED AREAS

PANEL 1110 OF 1575
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
SKAGIT COUNTY	530151	1110	E

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MAP NUMBER
53057C1110E

EFFECTIVE DATE

Federal Emergency Management Agency

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures.** Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 10. The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum.** For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/ or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC- 3, #9202
1315 East- West Highway
Silver Spring, MD 20910- 3282

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242,** or visit its website at http://www.ngs.noaa.gov/.

Base map data was provided by Skagit County GIS. It was created from available public records and existing map sources dated 2001. Road centerlines were derived from orthophotos dated 2001 and 2006 as well as from Skagit County GPS information.

This map reflects more detailed and up- to- date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables *in the Flood Insurance Study report (which contains authoritative hydraulic data*) may reflect stream channel distances that differ from what is shown on this map.

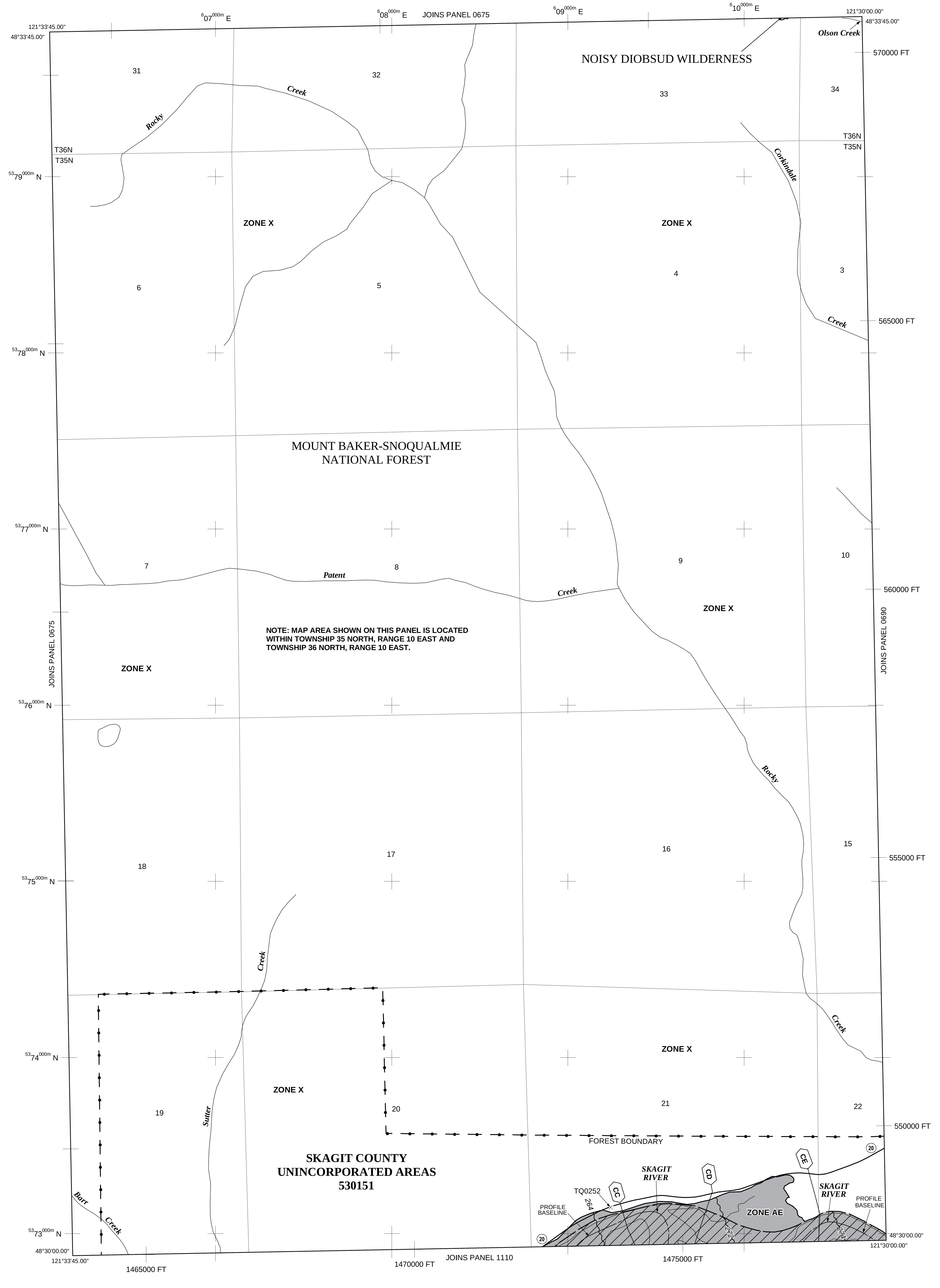
Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de- annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

Contact the **FEMA Map Service Center** at 1- 800- 358- 9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, *a Flood Insurance Study report*, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1- 800- 358- 9620 and its website at http://www.msc.fema.gov/.

If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1- 877- FEMA MAP** (1- 877- 336- 2627) or visit the FEMA website at http://www.fema.gov/.

The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the FIS report. As a result of improved topographic data, the profile baseline, in some cases, may deviate significantly from the channel centerline or appear outside the SFHA.



LEGEND

	SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

	Floodplain boundary
	Floodway boundary
	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
~~ 513 ~~~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

(A)———(A)	Cross section line
(23)- - - - - - - -(23)	Transect line
97°07'30", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
$^{42}75^{000m}$N	1000-meter Universal Transverse Mercator grid ticks, zone 10
6000000 FT	5000-foot grid ticks: Washington State Plane coordinate system, north zone (FIPSZONE 4601), Lambert Conformal Conic
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1- 800- 638- 6620.

MAP SCALE 1" = 1000'

500 0 1000 2000 FEET

300 0 300 600 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0670E

FIRM
FLOOD INSURANCE RATE MAP

SKAGIT COUNTY, WASHINGTON
AND INCORPORATED AREAS

PANEL 670 OF 1575

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
SKAGIT COUNTY	530151	0670	E

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
53057C0670E

EFFECTIVE DATE

Federal Emergency Management Agency